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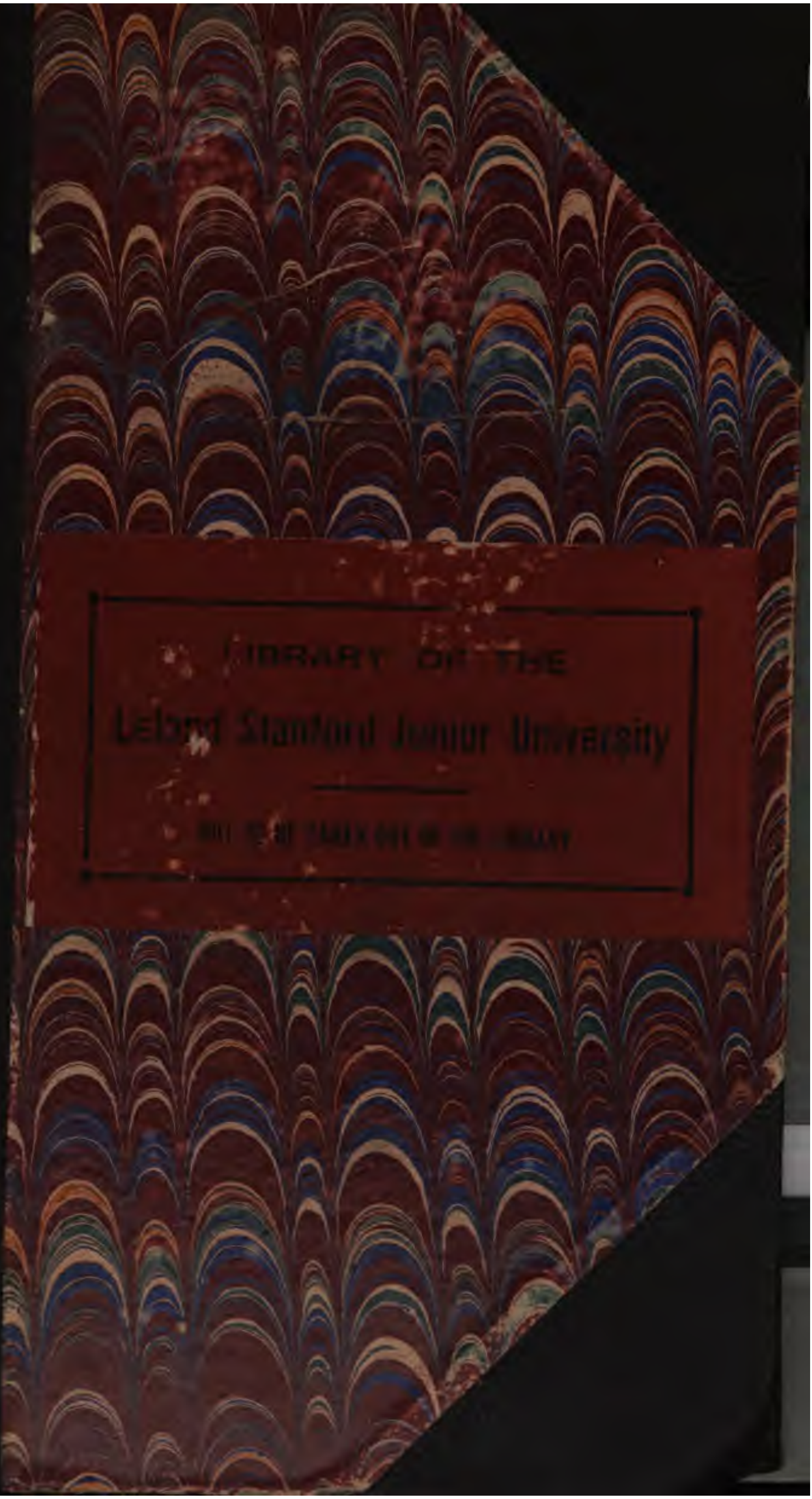

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ON

THE MAINTENANCE AND RENEWAL OF PERMANENT WAY.

BY

R. PRICE WILLIAMS, M. INST. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E.,
SECRETARY.

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speed of twenty miles an hour, at once proved too much for the first permanent way of the Liverpool and Manchester Railway; since its light, fish-bellied rails were quickly replaced by others of a heavier character, uniform in depth, of the section so well known as the double T-headed rail.

It is not the purpose of this Paper to give a history of the numerous inventions which have from time to time been brought forward for improving the permanent way. It is enough to say that, so far, none of them have realised the desired object; for, with the exception of the now generally-adopted method of fishing the ends of the rails, the substitution of wooden sleepers in the place of stone blocks, and the employment of a heavier class of material, the original system, introduced thirty years since, still remains in use. Accumulated experience now seems to show, that it is not so much by any ingenious or more scientific disposition of the materials employed, nor by the substitution of iron alone in the place of the more elastic and perishable substructure, that a corresponding improvement must be looked for in the condition of the permanent way; but rather to the judicious and liberal use of a better and more durable class of materials. For the failure of the iron sleeper road no higher authority can be quoted than Mr. W. H. Barlow, himself the inventor of the well-known saddle-back rail, which, from its originality, and the combination of scientific principles displayed in its design, at once recommended it to extensive adoption. Mr. Barlow, during a discussion in this Institution, candidly admitted its failure, and further stated his deliberate opinion that, "on roads which had to sustain the heavy loads and great speeds of the main lines of this country the employment of timber was unavoidable."[1]

Without advancing any speculative opinions of his own, as to what is theoretically the best form of permanent way, the Author thinks it will be at once conceded, that no system can lay claim to any such character, which does not provide for a due amount of elasticity in the substructure, in order, as far as possible, to neutralise, or absorb, the momentum of the passing loads.

With a view of showing that the durability of the permanent way, and more especially what has been termed the 'life of a rail,' have been considerably over-estimated, and further with the object of supplying more reliable means for comparing the cost of maintenance and renewals on different railways, the Author has been engaged for some years in preparing, from the published reports and other reliable sources, with the assistance and full concurrence of the different railway officials, tables and diagrams relating to the following lines of railway, arranged according to their mileage in the order following:—

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 282.

1. The London and North Western.
2. The North Eastern.
3. The Midland.
4. The London and South Western.
5. The Great Northern.
6. The Lancashire and Yorkshire.
7. The South Eastern.
8. The London, Brighton, and South Coast.
9. The Manchester, Sheffield, and Lincolnshire.

These tables and diagrams show, for a period of nineteen years,

1st. The detailed charges usually comprehended under the head of maintenance and renewal of permanent way and works.

2nd. The number of miles maintained.

3rd. The train mileage.

4th. The gross tonnage, together with other information bearing upon the subject.

The information to be gathered from the reports prior to the year 1847 being of a very scanty and unreliable nature, the Author has not thought it advisable to carry his inquiries beyond that period.

The objection has been urged, in previous discussions on this subject, that the comparative cost of maintenance of permanent way is a problem incapable of satisfactory solution, on account of the great variation in the mode of keeping the accounts on different railways.[2]

To meet this objection great care has been taken to omit from the calculations, in all cases, items such as gatekeepers, police, &c., ordinarily considered as traffic charges, but occasionally found included under the head of permanent way. Similarly, repairs to harbours, docks, telegraphs, canals, and other works unconnected with the permanent way, have, wherever they have appeared, been excluded. By this means, and by adopting the following general classification of the different charges usually comprehended under the head of "maintenance and renewal of way and works," it is hoped that sufficiently detailed information is furnished, in each instance, to enable a general comparison to be made, and at the same time to afford an approximate idea of the expenditure which has occurred, during a considerable period, on some of the principal lines in this country:—

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[1] *Vide* **Minutes** *of Proceedings Inst.* C.E., vol. ix., p. 387; vol. xi., pp. 282, 292, 297.

First, Maintenance of Way, including wages, materials, ballast, &c., is indicated on the diagrams (Plates 1 to 6) by the portion coloured *blue*.

Second, Staff and other charges, including superintendence, assistants, inspectors, office, and other charges, are indicated by the *white* portion.

Third, Works of Line, including repairs of gates, fences, roads (not at stations), slips, culverts, &c., and repairs (and occasionally renewals) of viaducts, bridges, and tunnels, are indicated by the portion coloured *green*.

Fourth, Stations and Station Works, including repairs to sidings, houses and buildings, stations, approach roads and yards, points and crossings, and gas and water service, &c., shown by the portion coloured *yellow*.

Fifth, Renewals of Way, including all materials and labour (occasionally materials only), shown by the portion coloured *red*.

In the Midland and the London and South Western accounts, maintenance of way, and of works of line, are included under one head. As, however, these items immediately follow each other in the order of arrangement of the tables, it is only necessary to combine them for the purpose of comparison with the other tables and diagrams. The lowest full hard line on diagrams 1 to 9 (Plates 1 to 6), shows the cost per mile per annum during each half-year of ordinary maintenance of way, including wages and materials. In some cases, it will be observed that wages and materials are shown separately, in others combined. The next line above shows the staff and other charges; the third, coloured green, the works of the line; the fourth, station works. The topmost line shows the annual cost per mile for renewals during similar periods, and at the same time shows the aggregate cost per mile per annum of the whole of the charges included under the head of "maintenance and renewals of way and works."

The stars (* * * *) on the diagrams indicate the number of miles maintained, to a scale of $\frac{5}{8}$ths of an inch to 100 miles. The dotted lines (—.—.—.) the train mileage, to a scale of $\frac{5}{8}$ths of an inch to a million miles. The vertically scored line with the white stars shows the gross half-yearly tonnage. The diagonally scored line shows the cost per mile per annum of renewals, according to the amount set aside for that purpose in the suspense accounts.

Taking the London and North Western Railway (diagram, No. 1, Plate 1), by way of illustration, it will be noticed, that in 1847 the number of miles maintained amounted, at that early period, to 378½ miles; that the cost of the first item, "maintenance *of way," had reached* £270 per mile per annum; and that that of the second, "staff and other charges," preserves throughout, down to the present time, a very regular and even outline. The third item, however, "works of line," shows considerable variation, due, probably, in a great measure, to the heavy and exceptional expenditure at times in replacing the timber viaducts, repairing slips, &c. The next item, "stations and station works," also exhibits the same variable character. It is, however, in the last item, "renewals of way," that the principal disturbance of outline is most noticeable. Already, in 1847, the permanent way of this line —which may justly be termed the parent of the English railway system, since it had its origin in the Liverpool and Manchester Railway—showed evident signs of rapid deterioration, as the cost of renewals, at this early period, amounted to £38 per mile per annum. It rapidly advanced during the following five years, until in 1851, it reached £101 per mile, and the total expenditure in renewals attained £132,502. Taking the cost of renewing a mile of single way (allowing credit for old materials, and exclusive of ballast) at the liberal average of £1,400 per mile, this would represent something like 94½ miles of single line, or about one-seventh of the whole double mileage maintained in 1847, entirely renewed during that period. In the next five years, from 1852 to 1856 inclusive, the cost of renewals advanced to just £200 per mile per annum, and the expenditure during this second period amounted to £630,001; equivalent to about 450 miles of additional single line—a length which, with the 94½ miles renewed in the preceding five years, corresponds to two-thirds of the whole double mileage (378½ miles) maintained in 1847 renewed in ten years. In the following five years, from 1857 to 1861, the cost of renewals averages nearly £200 per mile per annum, while the expenditure in this third period has amounted to £599,139, or to about 428 more miles of single line; the aggregate expenditure during the fifteen years having reached the large total of £1,341,662. In the remaining three and a half years, from December, 1862, to June, 1865, the cost of renewals has averaged £151 per mile per annum; while an additional outlay during that period, of £545,216, has been incurred, representing about 389 more miles of single way, forming altogether, in the nineteen years, a grand total of £1,906,858, expended on renewal of way alone, and representing something like 1,363 miles of single line, or almost half the whole mileage maintained in the year 1865.

It will further be observed that the average annual expenditure of this Company for renewals since 1847 has amounted to £103,074. This represents something like 73 miles of single way of the main line broken up and entirely replaced annually during this period; chiefly in situations where the traffic was heaviest, and where consequently (owing to the short intervals between the trains), the facilities for doing the work are the least, and the danger of accident the greatest.

In a report to the Directors of this railway some years since, the result of an elaborate inquiry into the question of the durability of the permanent way, by the officials of that line, the average life of a rail was stated to be about twenty years. This estimate, however correct when based on the circumstances and conditions of the traffic at that time, certainly does not seem to be borne out by the facts shown in this Paper. The average cost per mile per annum during the period of about nineteen years referred to is £145. Dividing £2,800, the average original cost of a mile of double line of permanent way, by this amount, the average life of a rail for the whole of the mileage maintained is found to be nineteen years. A large portion, however, of this mileage was not in existence nineteen years since—a considerable mileage, indeed, having been opened within the last few years, while another large part (about ten per cent.) is represented by single branch lines, many of them of comparatively light traffic. It may, therefore, be safely assumed, without pretending to be in possession of any specific or detailed information on the subject, except such as is afforded by the reports, that this vast expenditure has occurred on a very limited portion of the mileage. Probably, (as will presently be shown to be the case on a neighbouring railway,) it represents the renewals and re-renewals of those portions of the main line where the traffic is heaviest.

The average cost of renewals, per mile per annum, during a period of years, on the other railways is as follows:—

		Per Mile per Annum.
1. London and North Western Railway . .	(average of 18½ years)	£145
2. North Eastern Railway	(„ 14 „)	£83
3. Midland Railway	(„ 17½ „)	£84
4. London and South Western Railway . .	(„ 11 „)	£72
5. Great Northern Railway	(„ 9½ „)	£110
6. Lancashire and Yorkshire Railway . . .	(„ 16½ „)	£156
7. South Eastern Railway	(„ 15½ „)	£102
8. London, Brighton, and South Coast Railway .	(„ 12½ „)	£94
9. Manchester, Sheffield, and Lincolnshire Railway	(„ 9 „)	£49

The limits of this Paper will not permit a similarly detailed reference to be made to the other tables and diagrams. It is hoped however, that, being arranged on the same plan and to the same scale, they will, with the illustration just given, sufficiently explain themselves, and with the tabular statement showing the average cost of renewals, afford the information necessary for the purposes of general comparison.

Whilst the results afforded by the diagrams and tables 1 to 9 are sufficient, it is imagined, to show in a general way, that the rate at which the renewals of permanent way have been going on is more rapid than is usually thought, it must be admitted that they are too general in their character to afford a reliable estimate to be formed of the life of a rail. The Author, however, having some years since had charge of a district on the Great Northern Railway, has been enabled, through the kind assistance and co-operation of its chief Engineer, Mr. Johnson (M. Inst. C.E.), to supplement the tables and diagram, No. 5 (Plate 4), showing the cost of maintenance and renewals on that railway, by longitudinal sections of the two principal divisions of the main line (Plate 7), showing the particular parts of the line at which the renewals have occurred, the periods of renewal, and the nature of the different geological formations traversed by the line.

The Author is greatly indebted to Mr. Johnson and the other chief officers of the Great Northern Railway, for the unreserved manner in which they have afforded him information relating to the past and present condition of the permanent way of that railway.

It may be sufficient to mention, that the Great Northern Railway was opened throughout in the year 1853, the East Lincolnshire and Loop Line, together with portions of the main line between Retford, Doncaster, and Askerne Junction, having been opened for traffic in the four preceding years. This Paper, however, has chiefly to deal with the two principal divisions of the main line—the South, extending from King's Cross to Peterborough (75½ miles), and the North, from Peterborough to Askerne Junction (84¾ miles), Plate 7. Here it is that the destructive effects upon the permanent way of a large and concentrated traffic—more especially of a heavy and rapid coal traffic—are most significantly evident. The original rails laid down in 1853 were of a double-headed, reversible section, 72 lbs. to the yard, in 18 feet lengths, with joint chairs weighing 40 lbs. each, and intermediate chairs, 21 lbs. each, secured with two wooden trenails to triangular sleepers, each 13 inches by 6½ inches in section. The bottom ballast consisted of either burnt ballast, broken stone, chalk, or gravel, according to the geological condition of the district occupied. The top ballast was formed of gravel, and at the London end with burnt ballast. The latter, however, both from its destructive effects upon the sleepers, and its tendency, by retaining the water, to interfere with the efficient drainage of the line, was soon found to be unsuitable, and had to be replaced, in 1854–55–56, by good clean gravel. About the same time the joint chairs were to a considerable extent replaced by Adams's joint bracket chairs. These not being found to answer, were subsequently replaced throughout the whole of the main line with the present suspended fish joint. A single mile of this permanent way was estimated at the time to cost £1,450, credit being allowed for old materials, but exclusive of ballast.

The rails and chairs latterly used in renewing the road are of a heavier character, and the sleepers are of a rectangular scantling 10 inches by 5 inches, more befitting the increased weight and amount of the traffic; the rails are 82 lbs. to the yard, and 21 feet in length; the chairs weigh 35 lbs. each, have a broader seat, and are furnished with a wooden cushion for the rail to rest upon. These chairs are fixed to sleepers by means of two spikes and a trenail. The sleepers are placed 2 feet 8½ inches apart, centre to centre, except at the joints, where they are reduced to 2 feet, which is as near an approximation to a close planked road as the spaces required for packing will almost admit of. The cost of renewing a single mile of this road, as furnished to the Author by Mr. Johnson, is as follows:—

A Mile of Single Line.

	£.	s.	d.			
Rails, 503 – 21 feet = 3,520 yards, at 82 lbs. = 129 tons, at £8 14*s*.	1,122	6	0			
Chairs, 35 lbs. each = 63 tons, at £4	252	0	0			
Fish-plates, 503 pairs, at 25 lbs. = 5 tons 12 cwt. 1 qr. 3 lbs., at £8 14*s*.	48	16	9			
Bolts, 503 + 4 + 1½ lbs. = 1 ton 6 cwt. 3 qrs. 22 lbs., at £11 5*s*.	15	3	2			
6-inch keys, 4,024, at £5 2*s*. 6*d*. per 1,000 . .	20	12	5			
Trenails, 4,024, at £3 17*s*. per 1,000 . . .	15	9	10			
Spikes, 8,048, at 11 lbs. = 3 tons 11 cwt. 12 lbs., at £9	32	6	8			
Sleepers, 2,012, at 3*s*. 6*d*. each	352	2	0			
Cushions, 4,024, at £2 per 1,000	8	0	11			
Labour only, 1,760 yards, at 10*d*.	73	6	8			
Gross cost . .				£1,940	4	5

Credits.

Old rails, 3,520 yards, at 68 lbs. = 80 tons, worn out, at £4	320	0	0			
27 tons serviceable, at £5 10*s*.	148	10	0			
Ditto chairs, 3,520, at 21 lbs. each = 33 tons, at £2 5*s*.	74	5	0			
Ditto fish-plates, 503 pairs, at 21 lbs. per pair = 4 tons 1 qr. 7 lbs., at £5 10*s*.	25	18	8			
				568	13	8
Nett cost . . .				£1,371	10	9

January, 1865.

By reference to Diagram No. 5 (Plate 4), it will be seen, that for some time previous to the appearance of renewals in 1856, the large cost of maintenance clearly indicated that the rapid increase in the traffic—particularly the heavy through coal traffic—was beginning seriously to tell upon the condition of the road. To this cause, and to the cost of removing the burnt ballast, and to fishing the road, must be ascribed the high rate of maintenance at this period. The cost of renewal during the first half of the year 1856 was £35 per mile per annum; and about 2¼ miles of the up main line was relaid, on the descending gradients between Hitchin and London.

In December, 1860—seven years subsequent to the opening throughout of the line—the cost of renewals had reached £238 per mile per annum; and £158,800 had been expended in renewing about 134¼ miles of single line, including nearly the whole of the up and down lines between Hitchin and London, and the re-renewing of a portion of the mileage relaid so recently as 1856.

In the succeeding five years—1861 to 1865—181 additional miles of single line had been relaid, making altogether a total of 315 miles entirely renewed on the main line between King's Cross and Askerne Junction, at an expenditure of £423,280. Distributing this amount over the twelve years, the average annual charge is £35,273, equivalent to above 1 per cent. on the ordinary stock of the Company. In other words, the renewals which have been made on the 160¼ miles during the above-mentioned period have amounted to an average cost of £200 per mile per annum.

In order to account for the greater frequency of renewals on the up line, it should be explained, that the up traffic, including, as it does, all the heavy coal trains, exceeds that on the down line nearly in the ratio of 2 to 1; and, as might naturally be expected, the cost of maintenance and renewals will be found to be much in the same relative proportions.[1] It will further be observed, that the portions of the road which have most frequently undergone renewals are those on the falling gradients of the up line between Potter's Bar and London; clearly showing that it is to the great momentum acquired by the heavy goods and coal trains in descending those gradients that these destructive effects are chiefly due. This opinion is further confirmed by the fact, that on a similar rising gradient between the 63rd and 66th mile on the up line, the original rails still continue in place. Near the confluence of the different streams of traffic—for instance, at Hitchin and Hatfield—the frequency of the periods at which renewals have occurred becomes more strikingly apparent; most of the up line, on the descending gradients between Potter's Bar and Hornsey, has already undergone a third renewal during the short period of thirteen years, giving an average of only 3½ years as the life of a rail under these exceptional circumstances. Of the 160¼ miles of double road between King's Cross and Askerne Junction, there now remain, of the original rails laid down in 1852, about 77¼ miles of single way, chiefly, it will be observed, on that portion of the down main line between Retford and Peterborough, which, it will be remembered, was opened for traffic so late as 1853.

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[1] Up line 203 miles relaid.
Down line 112 „ „
315 „ „

Through the kindness of Mr. Grinling, the accountant of the Great Northern Railway Company, the Author has been enabled to ascertain, within very narrow limits of error, the actual weight and amount of the traffic which has passed over that portion of the line between Hatfield and London during the last 10 years. From this it would appear, that it required on the up line, near Barnet, 57,536 trains, and 11,760,926 tons, to destroy in 3 years the rails laid down in 1857; and 65,529 trains, and 13,484,661 tons, to destroy those laid down in 1860 and taken up in 1863.[1]

At the same time the Author is enabled, through the kindness of Mr. Meek, the chief Engineer of the Lancashire and Yorkshire Railway, to give the results of a most careful and elaborate investigation made by that gentleman, and extending over a period of 7¼ years, showing the comparative merits of different kinds of iron rails, supplied by some of the principal rail manufacturers of the country. A number of experimental rails of each make were laid continuously at the different stations, and these from time to time have been carefully examined, and the results noted. The number of trains and the tonnage that has sufficed to wear out these rails have also been carefully ascertained.

The results enable a comparison to be made with those just referred to; and the truth of the old saying, that 'it is the pace that kills,' is here very clearly exemplified; for the traffic on the Lancashire and Yorkshire, where the rails were laid down, although of a very heavy character, is slow, compared with that on the portion of the Great Northern line between Potter's Bar and Hornsey.

The results given by Mr. Meek show, that on the falling gradient of 1 in 130 at Ramsbottom viaduct, situated between Bury and Accrington, where the traffic is of a mixed character, 62,399 trains and a gross tonnage of 12,451,784 wore out the best sample of rails experimented upon in 7¼ years; while in the case of the Great Northern, just referred to, 65,529 trains, with a tonnage of 13,484,661, were sufficient to wear out the rails in 3 years. At Bolton, on the level, where the traffic is of a very heavy character, chiefly goods, and where all trains draw up, the same description of rails have required 203,122 trains and 38,803,128 tons to wear them out in the space of 7¼ years.[2]

That the rapid deterioration of the permanent way is in a great measure attributable to the increased weight and speed of the traffic these facts clearly show; and the concurrence of the tonnage outlines with the cost of renewals also bears a collateral proof of the truth of these deductions.

It is therefore evident that, with all the skill and care which have been displayed at various times, in strengthening and improving the permanent way, it has never at any period of its history been fully up to its work. The explanation of this fact is found in the simple reason, that the chief material, namely, the rails, is wanting in the essential element of durability. That this is so, the results of the experiments on the Lancashire and Yorkshire conclusively show; since the inherent defects, both of the best Yorkshire iron and the coarser and harder descriptions of Welsh manufacture, render them alike incapable of withstanding, for any length of time, the excessive wear and tear to which they are exposed.

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[1] *Vide* Appendix, Table 5.

[2] *Vide* Appendix, Table 7.

A reference to the mode of manufacturing iron rails will make this statement the more apparent. Plate 8 shows various methods of forming the pile, adopted at the principal iron works in South Wales. The pile, Fig. 1, is about 8 inches to 8½ inches square, in lengths according to the required dimensions of the rails. The top and bottom slabs, 2¼ inches thick, to form the table of the rail, are made out of a separate pile, 9 inches by 9 inches, of a better description of puddled bar, made from refined metal, having a highly crystalline fracture. This slab pile is twice heated before being rolled down to the dimensions of 2¼ inches. The interior of the rail pile is formed with No. 1 puddled bar, ¾ of an inch thick, arranged so as to break joint. The pile is then, with its top and bottom slab, heated to a welding heat, passed through the the bolting or cogging rolls, and reduced to a section of about 6 inches square. It is subsequently reheated, and rolled into the finished rail.

Figs. 8, 9, and 10 show the form of pile used by the Ebbw Vale Company for a quantity of rails supplied to the Lancashire and Yorkshire Railway Company. The quality of the iron is very similar to that used at the Dowlais Iron Works, Figs. 1, 2. and 3. A slight difference is, however, noticeable in the construction of this pile, by the insertion of the small pieces of No. 2 hammered puddled bars at the corners, so as to lap round the top table, as shown on the diagram, and at the same time to expose a more durable surface to the action of the tyre flanges.

Figs. 4, 5, 6, and 7 represent a different mode of piling, adopted at the Plymouth Iron Works, South Wales, whereby it is considered that greater uniformity is obtained in the structure of the iron. The base of the No. 1 puddled bar is as follows:—

Clay stone ore	25 per cent.
Hematite	50 „
Northampton	35 „
Forest of Dean	35 „

The No. 1 puddled bars, it will be observed, are formed into a pile of twelve layers of sufficient dimensions to enable it, when rolled down into a slab of 2¾ inches thick, to be cut into three pieces to form the No. 2 pile, which is afterwards rolled into the finished rail.

Another very common form of piling is shown in Figs. 11 and 12, where the old rails form the interior part of it, the top slabs being composed of No. 3 puddled bar. Figs. 13 and 14 show an ingenious method of piling with old rails, adopted at the London and North-Western Railway Works at Crewe, for the manufacture of steel-topped rails, the invention of Mr. F. W. Webb, (Assoc. Inst. C.E.)

The great objection to the form of pile in the two first instances, where crystalline iron or refined metal is used, is, that it is not of a sufficiently enduring character. The layers forming the tables of the rail are besides, when rolled down to the finished form, not more than ¼th or ⅜th of an inch thick; so that when, by the combined action of wearing and crushing, the thin top stratum is destroyed, the life of the rail is gone; the interior of the rail being of such inferior quality of material as to be incapable of any wear.

The other mode of piling, at the Plymouth Iron Works, has been adopted with the view of removing this objection, by making the pile throughout of a uniform quality of iron. It is a question, however, whether the desired object is thus obtained; whether the thin layers of ¾ of an inch of puddled bar are so thoroughly welded, and the scale so completely exuded, as not to cause the rail to laminate under the action of a heavy traffic. This has certainly been the effect observed in numerous instances which have come under the Author's notice. At the same time it is only right to mention, that cases have been observed, on the Great Western Railway, where iron rails of this particular manufacture have been exposed to the heavy main line traffic of that line for nearly nineteen years. Whether the rails were of a better material than those now manufactured is a question the Author is not prepared to answer. The fact, however, that very few makers are now disposed to give even a seven years' guarantee for iron rails, is tantamount to an admission, that where exposed to the excessive wear and tear of main line traffic their employment must no longer be looked for.

The introduction, within the last few years, of steel rails manufactured chiefly by what is known as the Bessemer process, and the highly satisfactory nature of the results obtained, encourage the belief that at length a material has been obtained which was alone wanting to give something like real permanency to that which in name only has hitherto deserved the title of permanent way.

In 1862, some steel rails were laid at the Camden Town and Crewe stations of the London and North Western Railway, where, from the excessively heavy character of the traffic, iron rails were usually worn out in the course of a few months. Two 21 feet steel rails laid on May 2nd, 1862, at the Chalk Farm Bridge, side by side with two ordinary iron rails, were, after outlasting sixteen faces of the iron rails, taken out in August 1865, and the one face only which had been exposed, during a period of more than three years, to the enormous traffic, amounting to something like 9,550,000 engines, trucks, &c., and 95,577,240 tons, although evenly worn to the extent of a little more than a quarter of an inch, still appears to be capable of enduring a good deal more work. A piece of one of these rails is, by permission of Mr. Bessemer, exhibited on this occasion. Another portion was entrusted by that gentleman to the Author, in order practically to test, by Mr. Kirkaldy's testing machine, how far its efficiency has been affected by the immense amount of traffic it has been exposed to. The results of this experiment, together with others which the Author has recently made on the comparative strength of steel, steel and iron (steel topped), and iron rails of different sections, have been carefully recorded by Mr. Kirkaldy, and are shown in Plate 9; while similar experiments on steel rails of various sections are recorded in Plate 10, and in Appendix, Table 12.

The general adoption of steel rails on main lines, where the traffic is of the heavy description referred to, will, in the opinion of the Author, not only prove cheaper in the end, but what is of infinitely more importance, will, through the less frequent breaking up of the road, materially add to the safety of the travelling public. It will also, in a corresponding degree, lighten the great weight of anxiety and responsibility which attaches to the resident Engineer, who, morally at least, is held accountable for all the accidents that occur through defects in the permanent way under his charge.

On the question of first cost, and on the relative advantages of steel at £15, and iron at half that sum, the Author does not propose at all to enter, further than to submit to the Institution the results of a most careful and elaborate calculation which Mr. Johnson (M. Inst. C. E.) has prepared (Appendix, Table 8). In this calculation he has very fairly estimated the life of an iron rail at the minimum of three years, alluded to as obtaining on portions of the Great Northern Railway, and on the other hand he has assumed the life of a steel rail at twenty years, the maximum period for which they have hitherto been able to obtain a guarantee.

From this it will be seen, that a balance of 50 per cent. is shown in favour of the steel rails, and this without taking into account the money value, which it is difficult to estimate, due to the increased safety in travelling and to the less frequent breaking up of the permanent way.

In conclusion, the Author ventures to suggest the desirability, at the present time, when the general introduction of steel rails seems probable, of arriving at something like a definite decision as to what really is the best form of section for the double-headed, bridge, and foot rails. At present not only has each Engineer his own particular views on the subject, and each railway its own peculiar section of a double-headed, bridge, or foot rail, as the case may be; but it frequently occurs that several varieties of section are in use on the same railway. It is thought that, with the aid of the experience which can now be brought to bear on this particular subject, standard types of rails might with advantage be uniformly adopted, suited to the different descriptions of traffic, and a great saving be effected, by a more judicious arrangement of the materials.

It only remains for the Author to state, that in venturing to bring this important question before the Institution, he has been influenced by an earnest desire to elicit an expression of opinion from Members who have had a large and varied experience in connection with permanent way, to whose judgment he, with all deference, submits.

The Paper is illustrated by a series of Diagrams, from which Plates 1 to 10 have been compiled, and by elaborate Tables, some of which will be found in the Appendix.

APPENDIX.

LIST OF DIAGRAMS AND TABLES ACCOMPANYING THE PAPER.

DIAGRAMS.

1.	London and North Western Railway	Cost of Permanent Way	Two sets to different scales.
2.	North Eastern Railway	Ditto	
3.	Midland Railway	Ditto	
4.	London and South Western Railway	Ditto	
5.	Great Northern Railway	Ditto	
6.	Lancashire and Yorkshire Railway	Ditto	
7.	South Eastern Railway	Ditto	
8.	London, Brighton, and South Coast Railway	Ditto	
9.	Manchester, Sheffield, and Lincolnshire Railway	Ditto	
A.	Longitudinal section of Great Northern Railway		Ditto
B.	Ditto Ditto		Ditto

C. D. E. F. F^a.	Diagrams illustrating manufacture of iron rails.
G. H. J. K.	Diagrams showing comparative results of vertical stiffness of iron and steel rails of various sections, as ascertained by Mr. Kirkaldy's testing machine.
L.	Diagrams showing results of experimental rails laid down on Lancashire and Yorkshire Railway.

TABLES.

1 A to 9 A	Tabular statements showing details of cost of maintenance and renewals of way and works of the nine different railways referred to on Diagrams 1 to 9.
10 A	Statements showing number and weight of trains on Great Northern Railway from 1856 to 1865.
11 A	Statements showing number and weight of trains on Lancashire and Yorkshire Railway from 1858 to 1865.
12 A	Statement showing a comparison between guaranteed iron rails at £7 15s., and estimated to last 3 years, with steel rails at £15 per ton, supposed to last 20 years.

C

List of the Tables in this Appendix.

Table 1. Summary of Mileage maintained, Increase of Mileage, and Amount expended in Renewals, with the Estimated number of Miles renewed on seven Lines, from June, 1847, to June, 1865.

„ 2. Ditto on nine Lines, from June, 1847, to June, 1864.

„ 3. Abstract showing amounts expended in Renewals of Way, Miles maintained, and Increase of Mileage, half-yearly, during a period of years, on various Railways.

„ 4. Abstract showing comparative cost per mile per annum of Maintenance of Way, Maintenance of Way and Works, and Renewals of Way, together with the cost per mile per annum of the total charges under the head of Maintenance and Renewals of Way, Works, Stations, &c., on various Railways.

„ 5. Statement showing the duration of certain iron rails on the descending gradients of the Great Northern Railway, between Hatfield and London; and on a similar ascending gradient between the 63rd and the 66th miles.

„ 6. Statement showing the number and gross weight of trains passing over the Great Northern Railway, from Hatfield to London, 1856 to 1865.

„ 7. Statement showing the number and gross weight of trains passing over certain portions of the Lancashire and Yorkshire Railway, from 1858 to 1865; with the average life of experimental rails at various stations.

„ 8. Statement showing a comparison between guaranteed iron rails at £7 15*s*. per ton, estimated to last 3 years, with steel rails at £15 per ton, supposed to last 20 years.

„ 9. Statement showing comparative per centage on gross traffic receipts, of locomotive charges, and maintenance of way and works, for a period of years, on the Great Northern Railway.

„ 10. Experiments on Bessemer steel rail, section 34, showing the relation between the carbon contained and the resistance to pressure.

„ 11. Results of experiments to ascertain the resistance to deflection and set under a gradually increased bending strain, of rails of various materials, form, and size, made at Mr. Kirkaldy's testing works.

„ 12. Results of experiments to ascertain the resistance to deflection and set under a gradually increased bending strain, of steel rails of various forms and sizes, made at Mr. Kirkaldy's testing works.

„ 13. Statement showing the separate and collective expenditure in renewals during a period of eighteen years on various Railways.

„ 14. Statement showing the cost at the end of each year from 1 year to 20 years (including compound interest at 5 per cent. per annum), of steel and iron rails, for 1 mile of single line.

TABLE 1.

SUMMARY of MILEAGE MAINTAINED, INCREASE of MILEAGE, and AMOUNT EXPENDED in RENEWALS, together with the ESTIMATED NUMBER OF MILES RENEWED, on SEVEN of the principal RAILWAYS, from June, 1847, to June, 1865, divided into Periods of Five Years.

DATE.	Mileage Maintained.	Increase of Mileage from June, 1847.	Amount expended in Renewals, in Periods of Five Years, from June, 1847.	Total Amount expended in Renewals, from June, 1847.	Estimated Number of Single Miles Renewed in Periods of Five Years.	Total Estimated Number of Single Miles Renewed from June, 1847.	Remarks.
			£.	£.			
1847 June .	1,385	..	..	..	..	..	
1852 „ .	2,322	937	367,203	367,203	263	262	
1857 „ .	3,036	1,651	1,631,735	1,998,938	1,166	1,428	
1862 „ .	3,951	2,566	2,013,086	4,012,024	1,438	2,866	
1865 „ .	4,612	3,227	1,419,937	5,431,961	1,014	3,880	3 years only.

Equal to 42 *per cent. of Mileage Maintained, June,* 1865.

SUMMARY showing the Total MILEAGE MAINTAINED, INCREASE of MILEAGE, and AMOUNT EXPENDED in RENEWALS, together with the Total ESTIMATED NUMBER of SINGLE MILES RENEWED, from June, 1847, to June, 1865, as above, apportioned among the Seven Railways named in their respective order.

NAME OF RAILWAY.	Miles Maintained in June, 1847.	Increase of Mileage, from June, 1847, to June, 1865.	Total Mileage Maintained in June, 1865.	Amount Expended in Renewals from June, 1847, to June, 1865.	Estimated Number of Single Miles Renewed, from June, 1847, to June, 1865.	Remarks.
				£.		Per Cent.
London and North-Western	378	837	1,215	1,906,859	1,363	= 50
North-Eastern . . .	300	810	1,110	867,576	619	= 28
Midland	377	301	678	775,950	555	= 41
London and South-Western	117	390	507	288,661	206	= 20
Great Northern . .	..	434	434	392,992	280	= 32
Lancashire and Yorkshire	76	305	381	768,924	549	= 72
South-Eastern . . .	137	150	287	430,999	308	= 54
Total . . .	1,385	3,227	4,612	5,431,961	3,880	= 42

TABLE 2.

SUMMARY of MILEAGE MAINTAINED, INCREASE of MILEAGE, and EXPENDED in RENEWALS, together with the ESTIMATED NUMBER o RENEWED, on NINE of the principal RAILWAYS, from June, 1847, 1864, divided into Periods of Five Years.

DATE.	Mileage Maintained.	Increase of Mileage from June, 1847.	Amount expended in Renewals, in Periods of Five Years, from June, 1847.	Total Amount expended in Renewals, from June, 1847.	Estimated Number of Single Miles Renewed in Periods of Five Years.	Total Estimated Number of Single Miles Renewed from June, 1847.	Re
			£.	£.			
1847 June .	1,551	..	..	..	..	..	
1852 " .	2,650	1,099	379,222	373,222	267	267	
1857 " .	3,376	1,825	1,758,209	2,131,531	1,256	1,523	
1862 " .	4,337	2,786	2,109,985	4,241,516	1,507	3,030	
1864 " .	4,881	3,330	978,883	5,220,399	699	3,729	2 ye

Equal to 38 *per cent. of Mileage Maintained in June,* 1864.

SUMMARY showing the Total MILEAGE MAINTAINED, INCREASE of MILE AMOUNT EXPENDED in RENEWALS, together with the Total ESTIMATED of SINGLE MILES RENEWED, from June, 1847, to June, 1864, as above tioned among the Nine Railways mentioned in their respective order.

NAME OF RAILWAY.	Miles Maintained in June, 1847.	Increase of Mileage, from June, 1847, to June, 1864.	Total Mileage Maintained in June, 1864.	Amount Expended in Renewals from June, 1847, to June, 1864.	Estimated Number of Single Miles Renewed from June, 1847, to June, 1864.	Re
				£.		Pe
London and North-Western	378	762	1,140	1,752,981	1,252	
North-Eastern . . .	300	795	1,095	803,265	574	
Midland	377	281	658	704,915	504	
London and South-Western	117	385	502	264,600	189	
Great Northern . .	..	421	421	335,388	239	
Lancashire and Yorkshire	76	297	373	674,330	482	
South-Eastern . . .	137	142	279	401,728	287	
London, Brighton, and South Coast . . .	121	111	232	212,954	152	
Manchester, Sheffield, and Lincolnshire .	45	136	181	70,238	50	
Total . . .	1,551	3,330	4,881	5,220,399	3,729	

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TABLE 5.

Statement showing the Duration of certain **Iron Rails** on the Descending Gradients of the Great Northern Railway between **Hatfield** and **London**; and on a similar ascending Gradient between the 63rd and the 66th Miles.

	Traffic over Gradient.	
	No. of Trains.	Tonnage.
Rails relaid, Dec. 1857 :—		
„ taken up, Dec. 1860 = 3 years	57,536	11,760,926
„ relaid, Dec. 1863 = 3 years	65,529	13,484,661
Gradient falling 1 in 200.		
Rails relaid, Dec. 1857 :—		
„ taken up, June, 1860 = 2½ years	47,445	9,679,078
„ relaid, April, 1863 = 2¾ years	58,851	12,116,382
Gradient falling 1 in 200.		
Rails relaid, Sept. 1860 „ sound, Jan. 1, 1866 } = 6 years	119,455	24,702,861
Gradient rising 1 in 200.		

TABLE 6.

Statement showing the Number and Gross Weight of **Trains** passing over the Great Northern Railway from **Hatfield** to **London**, 1856 to 1865.

Year.	Trains.	Number.	Weight.	Total of all Trains per Annum.	
				Number.	Weight.
			Tons.		Tons.
1856	Passengers	7,794	896,310		
	Goods	9,297	2,547,378	17,091	3,443,688
1857	Passengers	7,994	919,310		
	Goods	9,578	2,624,372	17,572	3,543,682
1858	Passengers	8,194	942,310		
	Goods	10,141	2,778,634	18,335	3,720,944
1859	Passengers	8,394	965,310		
	Goods	10,624	2,910,976	19,018	3,876,286
1860	Passengers	8,594	988,310		
	Goods	11,589	3,175,386	20,183	4,163,696
1861	Passengers	8,794	1,011,310		
	Goods	12,270	3,361,980	21,064	4,373,290
1862	Passengers	9,724	1,118,260		
	Goods	12,383	3,392,942	22,107	4,511,202
1863	Passengers	9,597	1,103,655		
	Goods	12,761	3,496,514	22,358	4,600,169
1864	Passengers	9,767	1,123,205		
	Goods	13,665	3,744,210	23,432	4,867,415
1865	Passengers	10,102	1,161,730		
	Goods	14,506	3,974,644	24,608	5,136,374
Total	Passengers	88,954	10,229,710		
	Goods	116,814	32,007,036		
				205,768	42,236,746

[TABLE 14.

nd Interest at 5 per

YEARS.	8 Years.							YEARS.
	£9. 10s.			£10.		0.		
	£.	s.	d.	£.	s.	s.	d.	
1	164	17	9	176	18	10	3	1
2	331	17	1	355	17	6	11	2
3	501	2	0	537	2	13	9	3
4	672	16	8	720	16	15	0	4
5	847	5	5	907	5	15	0	5
6	024	12	10	1,096	12	18	4	6
7	205	3	8	1,289	3	9	8	7
8	389	3	0	1,485	3	14	5	8
9	623	9	10	1,736	7	17	5	9
10	863	8	4	1,993	6	9	7	10
11	109	4	7	2,256	8	7	2	11
12	361	7	2	2,526	1	18	3	12
13	620	4	5	2,802	15	10	11	13
14	886	4	11	3,086	18	14	0	14
15	159	17	3	3,378	19	16	4	15
16	441	11	5	3,679	9	7	9	16
17	778	10	9	4,040	7	18	5	17
18	126	4	2	4,412	10	18	9	18
19	485	3	5	4,796	12	4	11	19
20	856	2	2	5,193	6	19	6	20

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TABLE 9.

STATEMENT showing COMPARATIVE PER CENTAGE on GROSS TRAFFIC RECEIPTS, of LOCOMOTIVE CHARGES and MAINTENANCE of WAY and WORKS, for a Period of Years, on the Great Northern Railway.

DATE.	Per Centage on Locomotive Charges.	Per Centage on Maintenauce of Way and Works.
June 1851	17·03	3·23
December . . . 1851	17·35	4·95
June 1852	..	..
December . . . 1852	14·24	4·80
June 1853	14·54	4·86
December . . . 1853	13·20	6·37
June 1854	15·61	9·12
December . . . 1854	15·18	7·30
June 1855	17·04	8·11
December . . . 1855	15·95	7·42
June 1856	16·31	8·69
December . . . 1856	14·50	7·73
June 1857	15·64	9·54
December . . . 1857	14·58	9·92
June 1858	16·88	10·18
December . . . 1858	15·14	8·46
June 1859	15·89	10·44
December . . . 1859	13·78	8·74
June 1860	16·10	9·32
December . . . 1860	14·51	10·40
June 1861	16·32	9·80
December . . . 1861	14·10	8·74
June 1862	15·50	8·98
December . . . 1862	14·76	9·22
June 1863	15·24	10·65
December . . . 1863	13·93	9·82
June 1864	15·80	10·74
December . . . 1864	14·76	10·08
June . . . 1865	16·94	9·99

TABLE 10.

EXPERIMENTS on BESSEMER STEEL RAIL, Section 34, showing
between the Carbon contained and the Resistance to Pr

The Rail was for the Great Indian Peninsular Railway Company, and the Experiments were made under the direction of Mr. G. Berkley, M. Inst. C.E., in August, 1864. The weight of Rail is 86 lbs. per yard. Distance between points of support = 3 feet 7½ inches.

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TONS.	1. Carbon = 40 per Cent.		2. Carbon = 46 per Cent.		3. Carbon = 49 per Cent.		4. Carbon = 50 per Cent.		C = 55
	Deflection.	Per set.	Deflection.	Per set.	Deflection.	Per set.	Deflection.	Per set	Deflection.
5	·04	·00	·03	·00	·04	·00	·02	·00	·02
10	·06	·00	·05	·005	·065	·00	·045	·00	·04
12½	·08	·005	·07	·01	·08	·00	·06	·00	·055
15	·10	·01	·09	·012	·10	·00	·08	·00	·07
17½	·127	·02	·12	·02	·12	·005	·10	·00	·08
20	·18	·05	·14	·05	·14	·01	·11	·00	·10
22½	·32	·18	·36	·14	·165	·03	·13	·01	..
25	·56	.40	·47	·32	·26	·10	·20	·06	·165
27½	·83	·65	·76	·59	·42	·24	·34	·175	..
30	1·10	·90	1·03	·83	·60	·40	·52	·33	·44
32½	1·53	1·30	1·34	1·12	·825	·60	·75	·54	..
35	1·96	1·71	1·66	1·41	1·05	·81	·97	·74	·79
37½	3·00	2·27	2·17	1·80	1·33	1·06	1·21	·95	..
40	3·94	3·74	2·64	2·34	1·64	1·35	1.45	1·18	1·37
42½	..	..	..	..	1·99	1·68	1·79	1·49	..
45	..	..	..	..	2·45	2·11	2·16	1·83	2·14
47½	..	..	..	..	3·25	2·87	2·73	2·37	..
50	..	..	..	..	4·18	3·77	3·68	3·28	3·42
52½	..	..	..	..	..	..	4·68	4·28	4·40

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Falling 1 in 50.	Hunt's Bar	7¼	1
Level . . .	Blue Pits	6⅛	1
Ditto . . .	Bolton .	3½	
Rising 1 in 150	Miles Platt	2½	
Falling 1 in 100	Wigan .	..	
Rising 1 in 88 .	Liverpool	6⅛	
Rising 1 in 200	Preston Cu	7¼	
Level . . .	Bury Tunn	7½	
	THORNE		
Falling 1 in 50.	Hunt's Ba	..	
Level . . .	Blue Pits	7¼	1
Ditto . . .	Bolton .	4¼	1
Rising 1 in 150	Miles Plat	4¼	1
Falling 1 in 100	Wigan .	..	
Rising 1 in 88 .	Liverpool	..	
Rising 1 in 200	Preston Cu	7¼	
Level . . .	Bury Tun	4½	

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2	4¼ Years. November, 1862.			5 Years. August, 1863.			6⅛ Years. October, 1864.			7¼ Years. November, 1865.		
1	Worn out.	Good.	Turned.	Worn out.	Good.	Turned.	Worn out.	Good.	Turned.	Worn out.	Good.	Turned.
		58,655 6,100,120			72,890 7,580,560			94,608 9,839,180			116,872 12,154,740	
	..	37	6	..	32	6	1	26	35	All.	..	..
	All.	..	..	..	..	..	..	..	..	..	..	..
(	5	..	3	6	..	2	All.	..	..	..	..	..
t	..	2	5	..	2	5	4	..	5	All.	..	..
	1	1	5	1	..	9	5	..	5	All.	..	..
v	..	6	1	..	6	1	1	3	2	All.	..	..
o	..	4	1	..	4	3	2	1	5	All.	..	..
		52,924 10,008,369			64,239 12,201,426			79,387 15,101,716			97,545 18,503,379	
•	..	2	5	..	2	5	3	..	5	7	..	All.
	..	2	4	..	2	5	..	2	5	7	..	All.
.	..	..	All.	..	..	All.	All.	..	..	..	..	..
-		29,397 5,433,491			34,309 6,278,116			42,461 7,768,290			50,703 9,305,594	
	4	..	4	4	..	4	5	..	All.	7	..	..
	3	..	4	4	..	4	5	..	3	7	..	..
	All.	..	..	..	..	..	..	..	..	..	..	..
	1	15	..	1	13	6	3	..	7	5	6	9
		29,184 5,376,396			34,431 6,311,024			42,400 7,752,105			49,305 8,929,397	
	1	5	10	5	..	6	6	..	10	8	..	All.
	2	6	8	7	..	3	7	..	9	11	..	All.
	4	..	2	All.	..	..	..	..	..	..	..	..
		33,975 6,665,074			41,001 8,078,354			52,134 10,370,372			62,399 12,451,784	
	6	1	1	7	..	1	7	..	1	7	..	1
	1	3	2	1	..	7	1	..	7	3	..	All.
	..	3	5	..	..	5	..	2	5	2	..	6
	All	good.	..	All	good.	..	All	good.	..	..	1	1
	..	..	2	1	..	1	1	..	1	All.	..	..
-		33,975 6,665,074			41,001 8,078,354			52,134 10,370,372			62,399 12,451,784	
	All.	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
	4	2	..	4	2	2	4	2	2	6	2	..

STATEMENT showing TEEL RAILS at £15 per Ton,

	s.	d.	
To 130 tons Rails, at £7 15s.			
Interest and compound			
per cent. per annum			
Ditto, old Rails, £1,007 10			
To labour for taking out the			
with new Rails at end			
Material 25 per cent. new			
5 per cent. new			
50 per cent. new			
Cr. By Old Bolts . . .			
Old Chairs . . .			
To interest and compound int			
By 118 *tons, old Rails taken o*			
To 130 tons Rails (for renewal			
Interest and compound int			
Ditto, of £1,007 10s. — £			
To labour, material, &c., for re			
Interest and compound int			
By 118 *tons old Rails taken ou*			
To 130 tons Rails (for renewal			
Interest and compound int			
Ditto, old Rails of £476 10			
To labour, &c., at the end of 9			
Interest and compound int			
By 118 *tons old Rails at the en*			
To 130 tons Rails, for renewal			
Interest and compound int			
Ditto, ditto			
To labour, &c., at the end of 12			
Interest and compound inte			
By 118 *tons old Rails at the end*			

[*Continued on the other side.*

.	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*	
	0										
2	6	1,371	1	6							
		531	0	0							
					846	1	6				
2	10										
7	0	1,283	9	10							
		531	0	0							
					752	9	10				
5	4										
2	0				458	3	4				
								6,708	19	5	**Unguaranteed Rails.**
								6,708	19	5	
8	7										
0	0							4,465	18	7	**Steel Rails.**
								2,243	0	10	**Balance in favour of Steel Rails in the cost per mile.**

on that value for 1 year (£531 = £25 6*s*.), divided by 3. Then, less one-third the cost

$$- \text{£25 6}s.\Big) - \frac{\text{£62}}{3} = \text{£146 12}s.$$

Mr. R. PRICE WILLIAMS said, as many of the experiments recorded in the Appendix had been completed since the Paper was written, and as the results had, he thought, an important bearing upon the subject dealt with, it had been considered desirable that he should briefly explain the diagrams, Plates 9 and 10, which embodied the results of various tests. In those diagrams, the uppermost horizontal line was divided by a scale of equal parts representing the pressure applied at the centre between the bearings, the vertical line similarly representing a scale of deflections in inches; but inasmuch as the latter was too large to allow of the results being shown upon one diagram, Mr. Kirkaldy determined, when he got to a certain point disappearing below the horizon, to reduce it, so that the other half of the diagram was to one-half the scale. In this way the whole of the deflections were shown on one diagram. In adopting 8 feet lengths of rails and 5 feet bearings, he had followed the system carried out by Mr. Francis Fox, M. Inst. C. E., in his interesting series of experiments on the vertical stiffness of rails.[1] There was this advantage in the 5 feet bearings—that the depth of the rail was just $\frac{1}{12}$th of the distance between the supports, being about the proportions of ordinary girders. The rails experimented upon were not sample rails obtained from the makers, but were chiefly supplied by Mr. Johnson, M. Inst. C.E., the engineer of the Great Northern Railway, and a few by Mr. Ramsbottom, M. Inst. C.E., from Crewe.

Commencing with the iron rails, the curved lines marked with the letters T, S, and R (Plate 9), represented the deflections of three sections of the bridge form of rail, and showed the least favourable results. For instance, the rail marked R, with a sectional area of 7·75 square inches, cracked through the bolt-holes with only an ultimate strain of 2,374 lbs. per square inch. The other two—which it would be seen were lighter rails—broke through the bolt-holes with considerably less ultimate strain.

The outline, Q, showed the deflection and point of fracture of a flange-rail of a smaller section, viz., 5·89 square inches; it snapped suddenly with the comparatively small weight of 4,915 lbs. per square inch, and showed a deflection of more than 3½ inches. The outline, P, represented the deflection of a light-sectioned Ebbw Vale double-headed rail of 6·83 square inches sectional area, the star showing the point of fracture: it broke with an ultimate strain of 5,230 lbs. per square inch. The next rail, marked M, was a heavy section of the same make, 8·17 square inches sectional area, and it suddenly snapped with 6,134 lbs. per square inch, and showed a deflection of 6·95 inches. There was a curious instance of two exactly similar deflections of two different rails; viz., P, which showed the ultimate breaking strain of the Ebbw Vale rail, and K, that of a steel-topped rail, which continued, it would be observed, in its deflection to the bottom of the diagram, and broke through the iron with an ultimate strain of 51,200 lbs., and the large deflection of 10·25 inches.

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[1] *Vide Minutes of Proceedings* Inst. C.E., vol. xx., pp. 259-274.

The next outline, marked L, showed the deflection and point of fracture of the present section of rail adopted by the London and North Western Railway, at Crewe; it cracked and canted with a strain of 6,254 lbs. per square inch. In form and sectional area this rail was nearly identical with the one last mentioned.

The next three deflections, marked H, J, and K, were those of steel-topped rails made after the plan adopted at Crewe. These showed higher results per square inch of ultimate strain than any of the iron rails. In the first instance the steel was subjected to compression, with 6,854 lbs. ultimate strain per square inch, when the iron was broken through, and torn up along the web, while the steel remained entire.

The next sample, marked J, was treated in the reverse way, the least favourable, of course, to the steel. The steel in this case was cracked through, the iron remaining intact.

He now came to the steel rails. The one marked G was peculiar only for the remarkably slight deflection it showed, amounting to only 0·86 of an inch, with an ultimate strain of 8,504 lbs. per square inch, and it broke suddenly. In connection with this hard form of steel rail he should mention that, through the kindness of Mr. Bragg, of the firm of Messrs. John Brown and Co., he had been supplied with the results of an interesting series of experiments, carried out, he believed, at the request of Mr. G. Berkley, and on which he hoped to hear something further, showing, as they did, the remarkable influence of a certain small increase in the proportion of the carbon (*Vide* Appendix, Table 10). The next rail, by the same makers, was equally remarkable for the other extreme of softness: for under a pressure of 8,263 lbs. per square inch it showed the large deflection of about 9¾ inches, and was canted and bent, but could not be broken.

The rails marked A, B, and D represented what he considered might fairly be taken as the average make of steel rails. The rail marked A, which showed the highest result of all the rails experimented upon, was supplied by Mr. Ramsbottom, from the Crewe works. It broke with an ultimate strain of 82,000 lbs. The sectional area was 7·67 square inches, and the ultimate strain per square inch was 10,453 lbs. The deflections of the next three rails, B, C, and D, it would be observed, preserved nearly the same outlines, and, in fact, broke with only a slightly less ultimate strain. There was one rail, however, marked E, which had not yet been referred to, and mention of which had been purposely reserved to the last: this was the famous Chalk Farm rail alluded to in the Paper. It occurred to him that it would be exceedingly desirable to ascertain, if possible, to what extent the serviceableness of this rail had been affected, by the enormous amount of traffic to which it had been subjected; and he asked Mr. Bessemer, to whom the rail belonged, to allow it to be submitted, along with other rails, to Mr. Kirkaldy's testing machine. At the time this rail was lying face to face with the seventeenth iron one, and it struck him, on examining it, that, if put to the test, it would still be found to have more life in it than any new iron rail. The result showed that, although it had sustained the enormous traffic of nearly 100,000,000 tons in three years, and had been worn away to the extent of more than a quarter of an inch, yet, after a continued strain of upwards of 10,677 lbs. per square inch, and after bending to the utmost limits allowed by the machine, it finally refused to be subjected to any further testing, and was canted in the manner shown in the rail itself which he exhibited.

Mr. W. P. STRUVÉ said, in speaking of the life of rails, it might be interesting if he described the process of manufacture which was adopted at the Cwm Avon Works in Glamorganshire, belonging to the Governor and Company of Copper Miners of England. These were not the largest works in Wales, but they made annually about 30,000 tons of finished rails, tin plate, and smelted and manufactured copper on a large scale. The process adopted was that of making unlaminated iron. The bloom now shown represented a block of unlaminated wrought iron, made directly from the refinery in the ordinary way, and after that run into another refinery, the refining process being continued till it became wrought iron. It was then taken out in a lump of 300 lbs. or 400 lbs. and placed under the steam-hammer. After being worked into a bloom, it was put into a heating furnace, re-heated and re-hammered two or three times, till it came out in the state it then was. In that condition it was ready to be rolled into slabs 2 inches or 3 inches thick. This unlaminated metal was used at these works for the purpose of 'topping' iron rails. The process of making the iron was a simple one, and not costly: one steam-hammer, two refineries, and two heating furnaces being capable of making about 60 tons of blooms per week. He could not at present give any important results of experience with this iron, because the process had only been introduced during the last twelve months. Some rails of that manufacture had been laid in the neighbourhood of London, and those which had been put down at Paddington were subjected to a traffic of 130 trains per day over them; and after having been down about twelve months, they as yet showed no signs of wear. At Cwm Avon he had placed them against rails made under ordinary specifications, and they had worn out two sets of the latter already.

With regard to the life of a rail, and especially of the Bessemer rail at the Chalk Farm Bridge, he was acquainted with the Bessemer process, which produced a wonderful metal; it ought, in fact, to be called a new metal. The Bessemer rail did, however, wear out. At Chalk Farm, in the course of three years, $\frac{3}{10}$ths of an inch had been carried away under the traffic that passed over it, or equal to $\frac{1}{10}$th of an inch per annum. In the Paper which had been read, the wrought-iron rail was spoken of as having a life of three years, while to the Bessemer rail a life of twenty years was assigned. Now, $\frac{1}{10}$th of an inch per annum would in twenty years amount to 2 inches, and in time the rail would go; but, as $\frac{3}{10}$ths of an inch had been worn off in three years, he thought seven years was as long a life as could reasonably be awarded to the Bessemer rail. He thought after $\frac{3}{10}$ths of an inch of metal were carried off in three years, or equal to $\frac{7}{10}$ths of an inch in seven years, the rail ought to be put by, and it might be a question, whether it would be safe to turn a rail after $\frac{3}{10}$ths of an inch were worn off. He did not contend that the class of rail of which he spoke would last as long as the Bessemer rail; but if the former would last five years and the latter seven years, then the cost of the Bessemer rails would be about £500 per mile per annum, and that of wrought-iron rails about £350 per mile per annum, for rails weighing 85 lbs. per yard. That divided over the traffic of any railway, would give the cost for rails per train per mile. He thought, from the consideration he had given to the subject, that $3\frac{1}{2}$*d.* per train per mile represented the permanent existence of a rail on a railroad for any amount of traffic, and he believed it ought to be well done for that. He did not, however, consider that the Bessemer rail could do it as cheaply; and he ventured to express the opinion, that railway companies, as a general rule, would not adopt, to any great extent, the Bessemer rail at £16 per ton. This might be a bold statement, but having had a good deal to do with the making of rails, he knew how closely Engineers looked at the price per ton. In South Wales, with all the pig-iron made there, there was scarcely any convertible into Bessemer steel; nor did he believe Bessemer steel could be welded to the ordinary wrought iron of Wales so as to make a safe weld. At the same time, he thought the Bessemer steel a most valuable metal for many purposes. If, however, an iron-master were offered 500 tons of old Bessemer rails and 500 tons of old iron rails, the latter would be the more readily taken; as he supposed old Bessemer rails would have to be put into the blast furnace, and be melted down, for conversion into something useful. After all, it came to a question of money; and it did not appear to him, that the Bessemer was likely to supersede the wrought-iron rail.

Mr. C. W. SIEMENS said, it had been asked, what was to be done with the Bessemer iron after it was worn out? He replied—melt it down, not in a blast furnace, but in a melting furnace, and make cast steel of it. He did not speak at hazard, for it was actually done by means of his Regenerative Gas Furnaces. M. Emile Martin was carrying out at Sireuil, in France, a process of melting scrap steel, sometimes Bessemer metal, in an open reverbatory furnace, which had been built by Mr. Siemens as a puddling furnace. This metal, when melted down, was used for steel tires of railway wheels.

With regard to the Paper generally, it contained a mass of valuable facts, which he thought would lead Engineers to a thorough knowledge of what they actually required, and that was nearly as valuable knowledge as the mode of carrying the necessary improvements into effect; because the remedy for a mechanical defect might, now-a-days, be almost regarded as the necessary consequence of its proved existence. His own interpretation of the facts and experiments brought forward in the Paper was, that instead of using laminated metal, which might be regarded as a bundle of iron wires soldered together by cinders, the metal used for rails and tires should be homogeneous; and that in order to get it thoroughly homogeneous, it ought to be cast. The Bessemer process gave a ready means of melting metal which was called steel, but which might with equal propriety be called homogeneous iron; because he believed that most of the Bessemer metal, such as was used for rails, contained not perceptibly more carbon than many ordinary sorts of iron; and if a bar of iron was melted into a homogeneous mass, the probability was the result would have been a metal not differing greatly from the Bessemer metal. In order to melt this metal, when not resulting directly from the Bessemer process, recourse must be had to another process, such as he had before mentioned. Speaking from his own experience, a ton of scrap steel could be melted with less than a ton of common slack, either on an open hearth or in crucibles; and this was, in his opinion, a satisfactory answer to Mr. Struvé's objection to steel rails, the cost of remelting the steel by this process being as small as that of re-rolling iron rails.

Mr. Fowler, President, inquired whether, if the Bessemer metal could be melted and used for tires, there was any reason why the same metal should not be remade into rails?

Mr. Siemens had merely stated a fact within his own experience, but he saw not the least objection to reconvert the Bessemer rails into cast steel rails, which would certainly be improved in quality by the transformation.

Mr. Vignoles, as a very early worker in the establishment of railways, had followed the various processes with great interest, and begged to offer one or two remarks. First he would inquire whether all these experiments had been made upon the same sections of double-headed rails, or whether other sections than the double-headed rail had been tested?

Mr. WILLIAMS replied, there were various sections of rails; but in the instance of the Crewe rails, which were double-headed, they were nearly all of the same section.

Mr. VIGNOLES remarked, that he was one of those who held that the double-headed rail was not the best form of section. For this he had contended for nearly thirty years, although he had himself received a premium from the London and Birmingham Railway Company for recommending it; but he had scarcely given that opinion when he found cause to repent it. So far in practice as he had had opportunity of observing it, the double-headed rail did not answer the intention he once thought it would, and such was still the conviction of those who advocated it, viz., that they had only to turn it and make use of the lower surface. Experience showed that, after seven or eight years' wear, the double-headed rail, if turned, snapped almost immediately; and on referring to the records of the Institution, the particulars would be found of the circumstances under which double-headed rails, when turned after a few years' wear, broke suddenly. But that was not the only objection. The Author of the Paper had expressed wonder, that there had been so little improvement in the permanent way. There could be no improvement in the permanent way so long as chairs were used, a complication of construction which had been long ago abandoned in every country but England, in favour of the flat-bottomed rail. With a rail weighing 80 lbs. per yard, and chairs 35 lbs. each, it would be found that the chairs constituted about 25 per cent. of the weight of iron employed. Now, if that were applied in adding to the weight of the 82 lb. rail, a rail could be obtained of nearly 100 lbs. weight. Without going into the question of the quality of different materials, having had little or no experience in the Bessemer rails, he argued upon the principle, that the double-headed was not the best form of rail, because it necessitated the use of the chair, which involved a complication of parts, required a wooden plug to keep the rail steady, and the chairs had to be fastened to the sleepers. The fishing of the rails was the greatest improvement that had been made, but that was not an English invention, as long before it was used in this country he had seen it abroad. It made the rail continuous, while the chair led to a dislocation at every sleeper. Those who recollected the old system of construction must be aware, that the jolting was due to the chairs, and where it existed now it could be traced to the chairs. If the Author sought improvement in the permanent way, he must begin by abandoning the chair. He could understand that improvement in the quality of the iron would tend to the improvement of the permanent way; but if the weight of the chairs now in use was added to the rails, and better rails at a very little larger price were obtained, then there would result a better road that would be kept in order at less expense.

As to the iron being homogeneous: looking at the modern specifications for rails—particularly those for Russia—a guarantee of six years for the rails was required. The specifications were incompatible with anything homogeneous; as the rails were to be excessively hard at the top, and elastic, or capable of extension, at the bottom. Homogeneous iron could not fulfil those opposite conditions; and herein was the difficulty of constructing the modern rails, as it was desired that the piles should be arranged in such a way, that the fibrous parts might be at the bottom and the crystalline parts at the top. The difficulty was to make the two piles meet, and to define how far the fibrous part should extend up the stem, and how far the crystalline part should go to meet it. However desirable it might be to use homogeneous metal for rails, it would not fulfil the requirements of modern specifications.

He urged that the double-headed rail was not one which modern practice and modern simplicity required. The great essential of the permanent way of a railway was, that it should be composed of the smallest number of parts. He thought by fishing, by dispensing with chairs, and by adopting the flat-bottomed form of rail, in which the greatest strength to resist deflection was found, that the greatest improvement in the permanent way would be arrived at; but it was impossible for any one to be led away with the hope, that the cost of maintenance could be much diminished. The constant increase in the weight of engines and the weight of traffic could only be met by a certain degree of elasticity in the road. It was a fight between the rail and the train, and there must be a certain amount of residual damage, which could only be kept up by a proportional renewal and proportionate expenses. If that could be diminished in any degree it was desirable that it should be done; but he did not think the modern practice would enable the expenses of maintaining the permanent way to be reduced in any material degree.

Sir Charles Fox agreed with Mr. Siemens that, although it was a matter of great importance to get a harder and a better quality of material for these purposes, it was, in his opinion, of still greater importance to get rid of iron rails, which, from being rolled from piles of bars, were only, in fact, bundles of rods. It was not only in these two respects that he felt it important to make rails of steel and perfectly homogeneous, but he thought it was desirable if possible to diminish the weight of the rails, by the use of a superior description of metal. The top surface of a rail was that upon which the wheels ran, without the intervention of any spring or elasticity between those two things; consequently, he looked upon the rail itself, particularly as iron rails were now made with a slab on the top, as an anvil by which such slab or bar was hammered by the tire; and having examined, by means of a magnifying-glass, a vast number of rails that had failed, he had found that in almost all cases of what was termed lamination, the failures had most frequently arisen from the presence of some foreign matter between the bars which formed the pile from which the rail was rolled. Foreign matters might be of many kinds—rust on the surface, or dirt collected in moving the bars about the rolling-mill; but perhaps the worst of all was, when a drop of melted fire-brick fell from the top of the furnace upon the red-hot pile, which ran over it like oil, when all the hammering or rolling in the world would not cement those bars together; but they would be, as Mr. Siemens had remarked, cemented together by cinders only. He therefore thought it was a matter of the greatest importance, not only to make rails of good material, but to make them out of one piece of metal; and for that purpose he knew of nothing better than the solid ingot obtained by the Bessemer process, which by hammering was got into a convenient size and length for rolling into a rail. In cases under his own charge, he was taking care to have a little elasticity between the tire and the body of the wheel, so as to reduce as much as possible the effect of the sledge-hammer action of the tire upon the surface of the rail.

Mr. GEORGE BERKLEY, while not intending to express an opinion opposed to that which had fallen from Mr. Vignoles, thought the present state of practice had been rather exaggerated, inasmuch as he believed there was as large, or probably a larger, number of double-headed than of Vignoles' rails being made in this country. In the south of France, he had recently seen rails not double-headed being taken up, and double-headed rails with chairs being substituted. He intended to limit the purport of his observations on this subject merely to the question of fact regarding the general adoption of one form of rail in place of the other.

With reference to the observations which had been made about the Chalk Farm rail, an erroneous impression appeared to prevail. It was asserted in the Paper, that where iron rails lasted three years steel rails would last twenty years. Mr. Struvé—having overlooked the fact, that while $\frac{3}{10}$ths of an inch were being ground away from the surface of the Bessemer steel rails at Chalk Farm, there were no less than sixteen faces of iron rail destroyed—stated that in twenty years, at the same rate of wear, 2 inches would be worn away, which being clearly inadmissible, proved that a Bessemer rail was not capable of lasting twenty years. If however it was taken into consideration, that one face *of an iron rail* would in that position only last $\frac{1}{16}$th part of three years, the fallacy of this argument would be apparent. Three years was not the life of an iron rail in that position, but $\frac{1}{16}$th part of three years was the life of one face of an iron rail, and the life of twenty years assumed for a steel rail in that position must be reduced in the same proportion.

With regard to the Paper itself, he thought there could be no difference of opinion as to its value, or as to the labour which had been devoted to collect, arrange, and illustrate an immense mass of facts for the benefit of the profession, nor of the modesty displayed in the manner of stating this information. The Author had been content to suggest those points which were material for discussion. There were three points which seemed to him to be prominent. The first he took to be the life of the rail. Now they were very apt to regard life as a period of years; practically he thought the Author had regarded it in the true way. The value of life was represented by the work done; the Author had, therefore, in the Appendix to the Paper, tried to show what amount of work each rail had done, what amount of abrasion it had received, and, at the same time, the circumstances which would help, or detract from, the power of that rail to withstand that abrasion were stated. That seemed to be a philosophical way of dealing with the subject; and great credit was due to Mr. Williams for the care taken in arriving at these facts, which were of peculiar value, as enabling a comparison to be instituted between iron rails and those made of Bessemer steel.

The first case given was that of the rails on the Great Northern at Barnet, the life of which was three years, with a work represented by 13,484,661 tons passing over them. Another case was that of rails which bore the passage over them of 12,451,780 tons of traffic, and attention was then drawn to the fact, that this was on an incline where the traffic was of a heavy character, travelling at a comparatively high speed. On the line where the rails were not subject to the same abrasion, and where the speed was much less, the rails bore the passage of above double the tonnage of trains passing over them. Taking that advantageous case of the 38,803,028 tons, and comparing it with the instance of the steel rail, it would be found that the steel rail, which was not yet more than half worn out, had already borne 95,577,240 tons passing over it. He should have been glad to have heard what the ballast was, and what the whole circumstances were, the form of sleepers, length of bearing, &c., in each case.

The next point the Author remarked upon was as to the form of the rail. No opinion was given as to what was considered to be the best form, but it was suggested that the best form should be determined and be universally adopted. Now he was not an advocate for fixed rules; Engineers must exercise a discretion, and, under the circumstances presented in each particular case, must determine what was the best form of rail to lay down. The opinion was, no doubt, based upon the great variety of strains which rails of different sections had, by experiment, shown themselves capable of bearing; but he thought it should be considered, that rails were designed to meet different circumstances: for instance, with longitudinal bearings a rail was required which gave a large surface on the longitudinal bearer, and which was not called upon to act as a girder. This was a shallow rail, and, if not supported by the longitudinal timber, would appear inferior to the double-headed or the Vignoles' rail, which were more adapted to act as girders supported between the points of bearing. The statistics of the Great Western Railway showed, that rails of that form, which gave an inferior result, when tested as girders, had yet borne the traffic just as well as other forms of rail. Therefore he did not think one form was necessarily preferable to another, neither was it admissible to say—"This or that was the best form of rail, and ought to be adopted under all circumstances."

He had looked carefully through the Appendix, with the view of ascertaining if he could discover sufficient evidence of the superior strength of the Bessemer rails, and, if so, in what degree they possessed it? He had found only one instance where there was the same section of rail made of iron and of steel. Where that was the case, the test seemed to him to be, as a comparative test, a fair one. That was so with the Crewe new rails. The Crewe new rail, tested on 5 feet bearings, bore a strain of 10,453 lbs., when made of Bessemer steel, while the same section of Crewe new iron rail bore only 6,245 lbs. There was in this a manifest advantage in the strength of the Bessemer steel rail of something like 70 per cent.

He had abstracted from numerous experiments made for him upon rails the following average results:—

EXPERIMENTS WITH IRON RAILS.

Weight of Rail.	Makers' Name.	20 Tons.		30 Tons.				Greatest Weight.
		Def.	Per. Set.	Def.	Per. Set.	Def.	Per. Set.	
		Inches.	Inches.	Inches.	Inches.			
68 lbs.	Ebbw Vale Co.* .	·72	·58	2·13	1·96			
do.	Bolckow, Vaughan, and Co.† . . .	·67	·56	1·81	1·67			
	Patent Shaft Co.‡ .	·52	·37	2·71	2·58			
	3)	1·91	1·51	6·65	6·21			
	Average .	·63	·50	2·21	2·07			

* 82 Experiments.
† 80 ditto.
‡ 365 ditto.

EXPERIMENTS WITH STEEL RAILS.

Weight of Rail.	Makers' Name.	20 Tons.		30 Tons.				Greatest Weight.
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Tons.
68 lbs.	J. Brown and Co.*	·32	·15	1·72	1·20	3·87	3·45	38·7

*45 Experiments.
Greatest strain rail bore = 50½ tons.

EXPERIMENTS WITH IRON RAILS.

Weight of Rail.	Makers' Name.	25 Tons.		35 Tons.	
		Inches.	Inches.	Inches.	Inches.
85 lbs.	Patent Shaft Co.* .	·64	·51	2·17	1·92
do.	Ebbw Vale Co.† .	·56	·40	1·45	1·23
	2)	1·20	·91	3·62	3·15
	Average .	·60	·45	1·81	1·57

* 24 Experiments.
† 8 ditto.

EXPERIMENTS WITH STEEL RAILS.

Weight of Rail.	Makers' Name.	25 Tons.		35 Tons.				
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Tons.
86 lbs.	J. Brown and Co.*.	·26	·10	1·03	·79	3·82	3·45	45

* 18 Experiments.
Greatest strain rail bore = 64·5 tons.[1]

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[1] A piece of the same rail was experimented on, and 1 square inch area
of the web bore 50·5 tons per square inch tension.
and of the head „ 47·0 „ „ „

Def. of steel rail, with 20 tons	: def. of iron rail, with 20 tons	::	1 : 2	68 lbs. section.
Per. set " " "	: per. set " " "	::	1 : 3·3	
Def. " " 30 tons	: def. " " 30 tons	::	1 : 1·28	
Per. set " " "	: per. set " " "	::	1 : 1·72	
Def. of steel rail, with 25 tons	: def. of iron rail, with 25 tons	::	1 : 2·3	86 lbs. section.
Per. set " " "	: per. set " " "	::	1 : 4·5	
Def. " " 35 tons	: def. " " 35 tons	::	1 : 1·7	
Per. set " " "	: per. set " " "	::	1 : 1·9	

He thought that no one could fail to be struck with the circumstance of the large proportion of strength there was in the steel rail, when great pressure was not put upon it, though the strain was much larger than anything it would be subjected to in practice. The material was evidently superior, and it would be found to give a better result, under ordinary circumstances of practice, than the ultimate test seemed to indicate.

He had also, in order to satisfy himself on this subject, had pieces cut out of the rail referred to as bearing 64½ tons, and tested, to show what the tensile strength of the metal was. The strength of iron was considered satisfactory, if it bore a tensile strain of 21 or 22 tons on the square inch. A piece cut out of the web of this rail bore 50 tons per square inch tensile strain without breaking. A piece cut out of the top of the same rail bore a load of 47 tons. Other experiments gave the point where elongation was supposed to commence, and the tensile strength of the Bessemer steel of other rails. He must say he thought the strains where elongation commenced were high. The delicacy of the instrument was not sufficient to enable the first movement to be tested. The following were the results:—

TENSILE STRENGTH OF BESSEMER STEEL IN RAILS.

	Elongation commenced. Tons per sq. inch.	Broke. Tons per sq. inch.
Piece taken from web of rail (86 lbs.) (Brown and Co.)	22⅓	45½
Piece taken from head of same rail .	26⅓	44⅔
Piece taken from web of rail (86 lbs.) (Cammell and Co.)	24½	45½
Piece taken from web of rail (86 lbs.) (Cammell and Co.)	22⅓	33½
Piece taken from head "	24½	42⅔
Pieces from web.—3 experiments.		
Average breaking weight		41½
Pieces from head.—2 experiments.		
Average breaking weight		43½

The following table showed the results of some experiments on the tensile strength of Bessemer steel in plates:—

TENSILE STRENGTH OF BESSEMER STEEL IN PLATES.

	Elongation commenced. Tons per sq. inch.	Broke. Tons per sq. inch.
Section = ·625 × 1·55 = ·813 sq. inch	24½	46
Section ·59 × 1·68 = ·96 sq. inch	20½	43
Section ·54 × ·55 = ·73 sq. inch	20½	44·7
Section ·58 × 1·55 = ·899 sq. inch	22½	44·5

From these tests elongation began at an average of
22 tons per square inch.

The pieces broke at an average of
44½ tons per square inch.

Some plates, tested by Samuda Brothers, broke at = 43½ tons per square inch.

Average of 4 Experiments on steel tried in Holland :
The breaking weight was = 42 tons.

Average of 28 Experiments at Chatham on steel plates for 'Bellerophon :' .
Breaking weight = 39·807 tons per square inch.

Average of the whole number (37) of Experiments:
Breaking weight = 42 tons per square inch.

Having thus tested the power of the lower web of the rail to resist tension, it was equally desirable to know what the power to resist compression in the upper web would be. Through the kindness of Sir William Armstrong and partners, he had made some experiments upon the compression of cylinders of Bessemer steel of exactly 0·755 of an inch diameter, which was the only size experimented upon. The result of these experiments was to show, that there was a remarkable uniformity in the point at which permanent set could be discerned. The permanent set was ascertained by means of a delicate instrument, and he thought the perusal of these results would lead to the conclusion, that Bessemer steel of that form, being little more than one inch in height and ¾ of an inch in diameter, would support 18 tons per square inch before there was a permanent set. The cylinders exhibited had been subjected to a pressure of between 50 tons and 60 tons to the inch, and he stopped at that, as there was no object in going further.

EXPERIMENTS WITH STEEL CYLINDERS.

Experiment No. 1.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
5,000	2·232	1·032	
10,000	4·464	1·032	
15,000	6·696	1·032	
18,000	8·035	1·0320	
20,000	8·928	1·0315	·0005
22,500	10·044	1·0285	·0035
25,000	11·16	1·0230	·0090
30,000	13·392	1·0130	·0190
40,000	17·857	0·9750	·0570
50,000	22·321	0·9155	·1165
60,000	26·785	0·8380	·1940

EXPERIMENTS WITH STEEL CYLINDERS—*continued.*

Experiment No. 2.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·032	·001
15,000	6·696	1·032	·001
18,000	8·035	1·032	·001
20,000	8·928	1·029	·004
22,500	10·044	1·02	·013
25,000	11·16	1·012	·021
30,000	13·392	·996	·037
40,000	17·857	·944	·089
50,000	22·321	·87	·163
60,000	26·785	·783	·25
80,000	35·714	·572	·461
100,000	44·642	·563	·47

Ultimate diameter 1·09.

Experiment No. 3.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·032	·001
20,000	8·928	1·032	·001
22,500	10·044	1·03	·003
25,000	11·16	1·02	·013
30,000	13·392	1·01	·023
40,000	17·857	·963	·07
50,000	22·321	·903	·13
60,000	26·785	·82	·213
80,000	35·714	·668	·365
100,000	44·642	·564	·469

Ultimate diameter 1·062.

Experiment No. 4.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·031	
5,000	2·232	1·031	
10,000	4·464	1·031	
15,000	6·696	1·031	
18,000	8·035	1·03	·001
20,000	8·928	1·028	·003
22,500	10·044	1·015	·016
25,000	11·16	1·008	·023
30,000	13·392	·994	·037
40,000	17·857	·95	·081
50,000	22·321	·877	·154
60,000	26·785	·79	·241
80,000	35·714	·645	·386
100,000	44·642	·538	·493

Ultimate diameter 1·086.

Experiment No. 5.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·032	
5,000	2·232	1·032	
10,000	4·464	1·032	
15,000	6·696	1·032	
18,000	8·035	1·031	·001
20,000	8·928	1·029	·003
22,500	10·044	1·017	·015
25,000	11·16	1·01	·022
30,000	13·392	·995	·037
40,000	17·857	·953	·079
50,000	22·321	·88	·152
60,000	26·785	·793	·239
80,000	35·714	·65	·352
100,000	44·642	·548	·484

Ultimate diameter 1·077.

EXPERIMENTS WITH STEEL CYLINDERS—*continued.*

Experiment No. 6.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·033	
20,000	8·928	1·032	·001
22,500	10·044	1·015	·018
25,000	11·16	1·007	·026
30,000	13·392	·991	·042
40,000	17·857	·943	·09
50,000	22·321	·87	·163
60,000	26·785	·775	·258
80,000	35·714	·635	·398
100,000	44·642	·535	·498

Ultimate diameter 1·09.

Experiment No. 7.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·0325	·0005
20,000	8·928	1·032	·001
22,500	10·044	1·019	·014
25,000	11·16	1·01	·023
30,000	13·392	·998	·035
35,000	15·624	·975	·058
50,000	22·321	·88	·153
60,000	26·785	·803	·23
80,000	35·714	·649	·384
100,000	44·642	·543	·49

Ultimate diameter 1·083.

Experiment No. 8.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·0325	·0005
18,000	8·035	1·031	·002
20,000	8·928	1·03	·003
22,500	10·044	1·018	·015
25,000	11·16	1·012	·021
30,000	13·392	·997	·036
40,000	17·857	·955	·078
50,000	22·321	·888	·145
60,000	26·785	·8	·233
80,000	35·714	·648	·385
100,000	44·642	·546	·487

Ultimate diameter 1·08.

Experiment No. 9.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·0325	·0005
20,000	8·928	1·032	·003
22,500	10·044	1·018	·015
25,000	11·16	1·013	·02
30,000	13·392	·998	·035
40,000	17·857	·955	·078
50,000	22·321	·886	·147
60,000	26·785	·792	·241
80,000	35·714	·645	·388
100,000	44·642	·573	·46

Ultimate diameter 1·05.

EXPERIMENTS WITH STEEL CYLINDERS—*continued.*

Experiment No. 10.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·0325	·0005
20,000	8·928	1·032	·001
22,500	10·044	1·021	·012
25,000	11·16	1·012	·021
30,000	13·392	1·	·033
40,000	17·857	·95	·083
50,000	22·321	·896	·137
60,000	26·785	·817	·216
80,000	35·714	·667	·366
100,000	44·642	·562	·471

Ultimate diameter 1·06.

He would mention a further experiment which was made upon axles. Having heard that some cast-steel axles were being tested in an extraordinary manner, he thought he would try Bessemer steel axles by the same test, not supposing they would stand so extraordinary a force. The axles were 3¾ inches diameter in the middle and 7 feet 2 inches long, and were placed on bearings 3 feet apart. He subjected them to a series of blows from a 15 cwt. ball, falling through 5, 10, 15, 20, and 35 feet.

EXPERIMENTAL TESTS OF BESSEMER STEEL AXLES, AT THE ATLAS STEEL AND IRON WORKS, SHEFFIELD, JANUARY 9TH, 1866.

Carriage Axles.

The axle to be tested was placed upon bearings 3 feet apart; the falling 'tup' weighed 14 cwt. 3 qrs.

Experiment No. 1.

First blow, fall 5 feet, bent the axle 1⅞ inches.
Second " " 10 " " " 3¼ " total 5⅛ inches.
Third " " 15 " " " 5¾ " " 10⅞ "
Fourth " " 20 " " " 6⅛ " " 17 "
Fifth " " 35 " " " 8⅛ " " 25⅛ "

This axle could not be bent any further by a falling weight; there was not the least sign of any fracture.

Experiment No. 2.

First blow, fall 10 feet, bent the axle 4½ inches. This axle was then turned over, and the

Second blow, fall 15 feet, bent the axle to 1¾ inches beyond straight. The axle was then nicked in the centre with a cold chisel for the purpose of breaking it; and the

Third blow, fall 35 feet, broke the axle and caused the ends to ascend a considerable height, one part falling 55 feet away from where it was struck by the tup.

EXPERIMENTS AT THE CYCLOPS STEEL WORKS, SHEFFIELD, JANUARY 31ST, 1866.

Experiment No. 1.

Weight of tup 14 cwt., axle placed on bearings 3 feet apart.

First blow, fall 11 feet 6 inches, bent the axle 5¼ inches.
Second „ „ 17 feet, „ „ 6⅞ „ total 12⅛ inches.
Third „ „ 23 feet 6 inches, „ „ 8⅜ „ „ 20½ „
Fourth „ „ 36 feet, broke the axle.

Experiment No. 2.

First blow, fall 30 feet, bent the axle 12¾ inches, when it was turned over, and a Second blow, fall 30 feet, broke it.

Experiment No. 3.

First blow, fall 5 feet 3 inches, bent the axle 2 inches.
Second „ „ 10 „ 6 „ „ „ 5 „ total 7 inches.
Third „ „ 15 „ 9 „ „ „ 6½ „ „ 13½ „
Fourth „ „ 21 „ „ „ 6¾ „ „ 20¼ „
Fifth „ „ 30 „ „ „ 6¾ „ „ 27 „

No sign whatever of any fracture.

Experiment No. 4.

First blow, fall 10 feet 6 inches, bent the axle 4½ inches.

Second blow, axle turned over, fall 10 feet 6 inches, brought the axle back straight. It was afterwards nicked with a cold chisel, and a blow, with a fall of 25 feet, broke it into three pieces, one piece coming out of the middle.

It would be readily imagined that only good metal could have supported such a test.

As to uniformity, if a good article either in iron or steel was wanted, undoubtedly there must be a good material to start with, and the conversion must be made with proper judgment. Granting that, then there seemed a doubt on many minds, whether this material, so made, would be of uniform strength. It would not be perfectly uniform, neither would iron or any other metal be so in practice. Some boiler plates of iron, supplied by a firm of eminence, which he recently tested, would not bear a strain of more than 16 tons to the inch, and he rejected them. He had tested boiler-plates with 26 tons to the inch; therefore, uniformity did not seem to exist in iron. When there was a difference of 35 or 40 per cent. in the iron sent out by the best manufacturers, he did not think that uniformity could be looked for in Bessemer steel, or in any other material. But the experiments, as far as they went, showed that as much uniformity might be relied upon in that material as in others.

He had given the best information he had on this subject, but it was not that which the Members ought to be satisfied with. These facts, together with those which had been brought forward in the Paper, only showed the necessity of getting together a larger number of similar facts, and from that larger number to arrive at some approximation to the truth. With this view, he suggested that a series of experiments should be organized by the Council of the Institution, and should be carried out on such a correct and comprehensive scale, that they should command something like authority. By that means he thought great good might be done, and that the introduction of Bessemer steel into the structures of art of this country might be shown to be advantageous. He begged to place his services entirely at the disposal of the Institution for that object.

Mr. FRANCIS FOX fully endorsed all that had been said with regard to the value of the great mass of statistics that had been brought forward; at the same time he confessed, as an Engineer having charge of the permanent way of a railway, he felt a little disappointed in the Paper. The subject was no doubt a vast one, and he had hoped to hear a great deal about everything connected with the maintenance and renewal of the permanent way of railways. He had heard some valuable statistics, but they seemed to resolve themselves, almost entirely, into the question of the relative merits of steel and iron rails. Following up the remarks of Mr. Berkley, he would express a hope that such an inquiry would be carried out, not only with reference to the question of rails, but that it would be extended to those numerous other items which entered into the cost of the maintenance and renewals of a railway, and which he need not here enumerate. The Author had included in the statistics 'reconstruction' of works; for although the Paper was entitled "On the Maintenance and Renewal of the Permanent Way of Railways," the works and other items forming portions of what was ordinarily called the 'line account,' were given; that was to say, the whole expense of the maintenance of the structure of a railway. Mr. Fox would also have been glad, if there had been some statistics bearing on the whole question of the cost of the permanent way, and not confined to that of the wear of the rails only.

He did not know how these statistics had been arrived at, but all must agree, that the published reports of Railway Companies were not the most satisfactory sources for ascertaining the cost of the maintenance of railways, because there were so many different ways of stating things. Some companies charged renewals to a renewal fund, and he, like other Engineers who had charge of a railway, naturally turned to the 'line account,' and he was often astonished to find that a certain company appeared to maintain its permanent way on a very economical scale; but on turning to another part of the account, he probably found a 'renewal of rails' account, which stood debited with a large amount under that head. He had no doubt the Author had taken these things into consideration; but he should like to see detailed returns from every railway company, giving those statistics in a reliable form, both as to maintenance and renewals. Some persons called maintenance little more than packing, and jointing, and fencing, whilst others carried it much further; there seemed to be a great want of definition in points of that kind.

The most valuable part of the Paper appeared to him to be, that which gave a certain relation between the tonnage carried and the life of a rail; if the data were extended to other points also, he thought they would be extremely valuable.

With regard to the question of steel rails, he had prepared for his own guidance a statement as to the relative cost of steel and iron rails. It struck him there were two or three methods of estimating the value of steel as against iron rails; and he need not say, as the question was entirely an economical one, it was all-important on what principle the comparison was drawn. Take, for instance, 100 tons of steel rails at £16 per ton—viz., £15. 10*s*. per ton, cost price, and 10*s*. per ton for laying—lasting any given number of years, and bringing back £8 per ton when worn out; then take a like amount of iron rails at £7. 10*s*. per ton, and 10*s*. for laying, making £8 per ton. One method of estimating the annual cost would be to take the first outlay of £1,600, and to add the simple interest of that sum for the number of years' duration of the steel rails; to set against it as a credit the sum brought back by the old materials, and then divide the sum by the number of years' duration. That was a plan which appeared at first sight to be a correct one; but he was not at all sure it was so; and the more correct plan, perhaps, would be to carry on the operation for a series of years. He had calculated, as a matter of curiosity, on a term of a hundred years, and he had found some strange results to arise. It appeared that the cost in that case was a progressive one; and that instead of the average cost of iron rails lasting three years, being £173 or £174 per annum when reckoned for a term of three years only, it came to no less a sum than £493 per annum, when calculated for a series of ninety-nine years. Another mode of calculation, which he believed was in use with some Engineers, was to reckon what sum placed at compound interest would represent a given sum, available for renewals at the expiration of a given term of years. He thought, however, that that was not a correct mode of calculation, because the money was expended at the outset in the purchase of the rails, and it was therefore running at interest during the whole time of their duration. Moreover, he did not believe that compound interest ought to enter into the question; for if an Engineer, by the use of steel rails, saved £1,000 or £10,000 in any half year, the sum so economised went into the pockets of the shareholders as dividend, and was therefore not itself accumulating interest. This consideration was at the root of the whole question, viz., what would steel rails, as against iron rails, save in any given number of years? Taking the case of the 100 tons of steel rails at £16 per ton, even if they lasted for ever, they would cost £80 annually for interest. It could therefore be conceived that iron rails, lasting but a few years, might be quite as economical as steel rails lasting for ever. The table he had drawn out was based on the supposition of different periods of duration, and it enabled him to form a comparison between iron rails lasting a certain number of years and steel rails lasting a certain longer period of years. He should be obliged if the Author, before the close of the discussion, would state the principle of calculation on which his comparison of the cost of steel and iron rails was based. He would say, as an Engineer having chiefly to do with bridge rails, that he found considerable discrepancy between the results of the tests given by Mr. Kirkaldy and those contained in the Paper which he had presented to the Institution some years ago. He could not account for this discrepancy, because several experiments were tried by him with generally uniform results; at the same time it was not fair to test a bridge rail, supported at every point, in the same way as a double-headed rail, with only partial bearings on the chairs. By referring to the table attached to his Paper, it would be seen what was the strength of the bridge rail placed on longitudinal timbers, and it would be found that the two together formed an exceedingly strong system of girder. With regard to the use of steel rails, there was no question they would last out a number of iron rails. He had put steel rails down in situations where they showed scarcely any wear, and where iron rails were worn out in a few months. In such cases there could be no question whatever as to the advantage of using steel rails; but he thought there was a point at which it was more economical to use iron rails, looking at the difference in price. At the same time, steel rails were undoubtedly good for crossings and switches, which were subjected to a good deal of wear, and in such cases he used scarcely anything but steel.

Iron permanent way had been characterized by the Author as a failure; and in support of that view, Mr. W. H. Barlow's general condemnation of the Barlow rail had been quoted.[1] Now Mr. Fox did not agree in that opinion, because he did not think the system had had a fair trial; and he believed that if a better material had been used, and it had been differently jointed, that was, if instead of being firmly riveted together it had been jointed in a manner to allow of expansion and contraction, it would not have been condemned so strongly as it had been. Referring to another system of iron permanent way, of which 14 miles were laid upon the Bristol and Exeter Railway, a portion of it in 1853, he might state that there was no apparent deterioration of the base on which the rails rested, and he regarded that fact as proving his opinion, that if the base lasted so long, there must be some advantage in using iron as a base instead of timber, which under ordinary circumstances lasted only a comparatively short time. However, he did not advocate iron as a substitute for timber in all cases for the permanent way of railways. He might, however, state, for the information of the Institution, that a piece of iron permanent way which he laid in 1861, and which consisted of a bridge rail, laid upon a longitudinal T iron base 12 inches wide, with a rib projecting 3½ inches from the centre downwards, with a cushion of wood between the rail and the iron base, had proved the best system of iron permanent way that he had adopted. There were however certain defects belonging to any iron way; as for example, it required better ballast, and probably a little more labour in packing; the nuts were liable to give trouble by working loose, and it was more costly in the first instance. He had also tried the system known as De Bergue's iron way, and it succeeded better than he expected it would do. The breakage of chairs was only about one half per cent. per annum of the total number laid. It took a little more labour in packing, but made a very fair road; and with some improvements in the arrangement of the cross transoms, it might be made a good road. It was not more expensive in first cost than a timber road, and there was a saving of nearly the whole cost of the renewal of timber.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 259.

He trusted that this valuable Paper was only the commencement of a series of Papers which would enter into the whole subject, so important to the railway world, inasmuch as the aggregate cost of the maintenance and renewals of railways in the United Kingdom might be estimated at many millions sterling per annum, and anything that could tend to lessen this enormous cost must be of extreme value. He had always been an advocate for the longitudinal system of permanent way, and he found nothing in the accounts of other companies to lead him to think, that the longitudinal system of way was more expensive to maintain than the transverse system. He was, no doubt, in the minority amongst Engineers on that point; he was, however, open to conviction, and in conformity with the suggestion of the President, he should be happy to contribute towards the supply of any information bearing on this important and interesting question.

Mr. Vignoles said, allusion had been made to the difficulty of comparing the expenses of maintenance on different railways; and he thought there was nothing in which the Institution could do greater service, to the public and to railway companies, than in pressing upon the Government the importance of getting statistics in regard to railways as well as in other departments. In Germany the collection of statistics was most perfect, and there the minutest difference of cost upon the several lines could be traced. With respect to difference in the weight of metal, the Bessemer rail might undoubtedly be lighter than those now in use, and therefore credit should be given for the weight of chairs (where abandoned) to be added to the weight of the present very heavy rails, should the Bessemer rail be adopted.

Mr. ROCHUSSEN would endeavour to contribute a short chapter to the history of the life of rails, by the exhibition of two compound steel rails of early manufacture. He had tried to ascertain whether rails of that description had been made prior to the year 1854, but he had not been able to find any. These rails were laid at the Hamm Station of the Cologne and Minden Railway in February 1854. The line at this point was perfectly level, and the soil was loam. The rails were supported by oak sleepers 8 feet long, and 11 inches wide, by 6 inches thick, laid 3 feet apart, and the joints of the rails were supported, not suspended, and the elasticity of the line was increased by a bed of gravel 13 inches thick, under each sleeper. The iron rails at the Hamm Junction were found to have a life of barely two years; and a desire having been expressed to find a more durable material, the managers of the works with which he was connected, were consulted, as to whether steel could not be applied to the head of the flange rail, which was done with complete success. After having been laid eleven years, only one side of the head was slightly worn, and the other side was not touched. He was not able to state the exact weight of the traffic which passed over those rails, inasmuch as the Cologne and Minden, like most Prussian lines, only took account of the actual traffic of loaded carriages and trucks, not including the weight of the rolling stock or the running of empty carriages and wagons. The actual nett weight of traffic carried on the Berlin and Cologne portion of the line was stated to be about 12½ million tons: adding to that the weight of the trains, it would represent about 17½ million tons. They had besides a traffic from other lines, which had running powers over this railway, from north-west to south-east, and then again to the north, which might be estimated, independently of the empty carriages, at 30 million tons. These rails were 56 lbs. to the yard, and the steel used in the manufacture was only a thin slab of puddled steel of about ⅝ths of an inch; the steel portion forming only about 12½ per cent. of the whole section. The advantage of this combination he considered to be a degree of elasticity, where it was most required; the iron to resist the great strain through oscillation, and the steel to give greater durability to the head; and thus the rail, while more durable in itself, was less injurious to the axles and springs which ran upon it. It was, however, found, after some experience with this section of rail when combined with cast steel, that a mere facing of cast steel on the iron was not durable, and that to produce a complete combination of cast steel and iron, without desintegration by the vibration of the rail, it was necessary to have as a minimum 47½ per cent. of the section of steel. In comparing this manufacture with Bessemer cast steel, it might be asked why puddled steel had not been wholly used for the web and bottom of the rails. To this he would answer, that it was desired to have a certain amount of elasticity somewhere; and therefore in the new construction, iron was put in the bottom, although it properly belonged to the web. It could not at present be settled what these rails would do as compared with puddled steel, but they promised good results. A great deal depended upon the material itself. The name of Bessemer stood so high, that it would always be a landmark in the annals of iron manufacture. But that which bore the name of Bessemer metal was not always entitled to the hall mark of that good name. Unless good iron were used in the first instance, they could not have good steel; and he urged Engineers not to yield indiscriminately to the Bessemer metal, as it all depended upon the quality of the material employed.

Mr. Siemens had pointed out what could be done with the old Bessemer rails, viz., melted as scrap; but Mr. Rochussen might state there was a far better application than that—viz., simply to cut up the iron rails into proper lengths, roll them into billets and rods, and then draw them into telegraph wire. They could do this with good Bessemer steel up to No. 8 gauge wire; and as fencing and telegraph wire it was capable of very extensive application.

Mr. G. W. HEMANS said, as this discussion seemed likely to merge entirely into the question of the manufacture of rails, which should stand any amount of wear and tear, he was anxious, before it fell altogether into that groove, to arrest the attention of the meeting for a moment on the engineering principles which were to be regarded in the putting together of the permanent way, which he thought were distinct from the question of the particular manufacture of the rails. The Paper embodied a large amount of experience, collected from various sources, for which they were much indebted to the Author. There was one point with which he entirely agreed, viz., that the ingenuity applied to the engineering details of the permanent way had by no means kept pace with railway improvements in other matters—as in engines and rolling stock, the construction of bridges, &c.; but on the subject of the construction of the permanent way it had remained almost stationary, as, with the exception of the marked improvement of the fish joint, the permanent way at the present day was really almost what it was twenty years ago. It might appear presumptuous to bring forward his own experience in these matters on the few hundred miles he had constructed in Ireland and elsewhere, against the thousands of miles that had been constructed by more eminent men, still he ventured to think there was room for great improvement in the prevailing system of permanent way.

He would direct attention to the abstract principle of construction of the permanent way as it now for the most part existed. It appeared to him, that the ordinary permanent way, with cast-iron chairs, really consisted of a series of iron bars laid upon iron anvils, tightened up with wooden keys more or less loose, and with very small bearing surface. There must arise from that a great vibration and wear and tear of material; and his impression was, that a great deal of it arose from defective construction in this mode of putting together the permanent way. Under a heavy engine, there was a deflection of the rail between every chair on which the rail rested; and there was no doubt when the rails were turned, as they sometimes were, and which he thought was not a judicious operation, at every chair, where the bearing did not exceed 2½ inches on the seat, an indentation had occurred to something like ⅛th of an inch in the bottom seat of the rail. That could not arise without injury to the whole structure of the rail; and he thought it time that something was done to improve that construction. The cost of the ordinary form of permanent way, in which the rails were fixed with wooden keys into cast-iron chairs, compared with fixing the rails without cast-iron chairs, direct upon cross sleepers, was about £374 per mile in excess; that was, the chairs cost between £300 and £400 per mile. By that plan it was said the rails might be turned; but he thought that was not desirable. Many attempts had been made to do away with this system of permanent way. Mr. Brunel adopted the bridge rail laid upon longitudinal timbers. That system had not met with favour, partly, perhaps, because it was said that the drainage was not so good, and that longitudinal timbers decayed a little faster than cross-sleepers; but the great evil with the bridge rail, and he believed the reason it had failed, was, that it was impossible with that section to make a good joint. There was no mechanical contrivance which could be introduced to prevent the ends of the rails being driven into the timber when upon a flat plate, as efficiently as the ends of a double headed rail could be fished and supported. He believed that was one of the reasons why the bridge rail upon longitudinal timbers had fallen into disfavour.

He would mention a fact with regard to the durability of rails which had surprised him. Eighteen years ago, on the Midland *Great Western* Railway of Ireland, he laid about 30 miles of the

Vignoles rail, not, as was generally the practice, upon cross sleepers, but on longitudinal bearings. Last year the rails on the other portions of the line got into disrepair, and he was called upon to report on the subject. To his surprise he found the flat-footed rails, on longitudinal bearings, still in use and in good condition, and likely to last a few years longer. The only evil was, that the ends of the plates, on which the rails rested, had been indented into the timber and become loose, simply because fishing the joints had not been then discovered, and for that reason they were not so successful as they would otherwise have been. That experience was sufficient to show, that rails, properly laid, on longitudinal bearings, without the intervention of chairs, caused the pressure of the heavy locomotive to be transferred through the rail directly upon the ballast, and that that system of bearing would better sustain the heavy rolling weights now used, than the iron supports at short intervals with small bearings, and with the deflections which caused so much disturbance to the rail. He therefore believed that the flat-footed rail, sufficiently deep to allow of good fishing, though it was entirely out of fashion and forgotten in the present day, ought to be revived; and if the longitudinal bearings were of timber, well chosen, and well creosoted, whether the rails were of iron or steel, that would be a mode of construction best calculated to resist the enormous weights of rolling stock now used. At least 70 per cent. of the rails referred to as having been laid for eighteen years were still in good condition. Being a main line the traffic was considerable, though not equal to any of the great English lines, nor to be compared in point of weight of goods conveyed. Rails laid in the same situation, upon cast-iron chairs, would have been worn out seven or eight years ago. The traffic probably would not exceed thirty trains per day, including goods and cattle and all specials, in both directions.

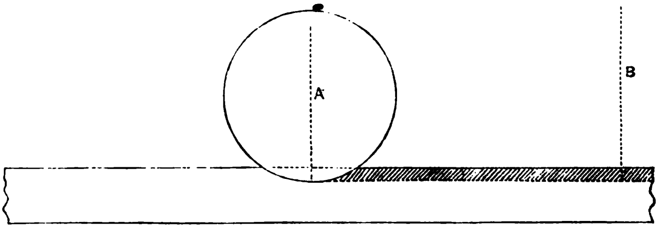
Mr. G. H. Phipps wished to mention, as a matter of history in connection with the competition offered in 1834 by the Directors of the London and Birmingham Railway Company for the best form of rail for that line, that he, in conjunction with Mr. Birkenshaw, sent in a design for a rail with a fish joint complete, as shown in the original wooden model which he now exhibited.

With regard to the immediate subject of the Paper, the Author had addressed himself more to the consideration of the rail alone than to the other component parts of the permanent way, probably because the rail was the only part of the permanent way on which the Author saw his way to improvement. The Author had gone largely into the merits of steel rails, and in the commendation which had been passed upon them, Mr. Phipps entirely concurred, and considered it amply supported by the experience with the steel rails laid at Chalk Farm. Having read carefully the observations in the Paper, corroborating the Author's views, by Mr. Johnson, and with the data given as to the price and duration of the rails, he quite concurred in the statement, that there would be a saving effected of 50 per cent. of the cost of iron rails. Having admitted that much, with regard to the excellency of steel rails, it was clear that it would be desirable to use them on lines with a large amount of traffic; but, prior to using steel rails on a large scale, he thought it desirable to determine, whether the amount of adhesion of the locomotive wheels with steel tires upon steel rails would be the same as between steel tires and iron rails, for that perhaps admitted of some question. He had hardly formed an opinion on it himself, but he thought it would not be prudent to use steel rails largely without determining that point.

With regard to the destructive effects of high speed upon the rails, from the information given by Mr. Meek, it appeared that with the same locomotive engines, and everything similar except variations of speed, the same rails required more than three times the traffic to wear them out at the lower speeds. There was no statement given of what the comparative speeds were; but he believed it would come out that, for equal quantities of traffic, the wear of the rails would be in the ratio—not of the velocity simply, but of the square of the velocity; a proposition which he thought would be found equally amenable to practice as to reasoning.

Assuming Fig. 1 to represent a railway wheel and rail, with a given weight upon the wheel, it would bed itself by actual compression a certain distance (shown by the etched lines) into the substance of the rail. All the matter shown by the etched lines would then have to be displaced by the wheel during the time of its passage from A to B (just as the water in its path was displaced by a vessel), and in proportion to the shortness of the time of passage would be the speed of displacement, the resistance being, therefore, as the square of the speed. Whilst upon the subject of the destructive effects of speed, he would refer to a letter, addressed some years ago, by Mr. G. R. Stephenson, to the President of the

Fig. 1.



Board of Trade,[1] as to the desirability of slow speeds upon railways for conveying mineral traffic. It was shown in that letter, that if the mineral traffic were separated from the passenger traffic, and a slower speed adopted for the former, it could be carried with much less destruction to the rails and rolling stock, and therefore with more economy. If the destruction was as the square of the velocity, and the line of railway abounded with inclined planes up-hill and down-hill, with a diminished speed up-hill and an increased speed down-hill, the wear and tear would be considerably greater, than if the same space were traversed at an uniform speed equal to the average speed.

The coal traffic on the Great Northern Railway, and its destructive effects upon the permanent way, having been particularized in the Paper, Mr. Phipps could not forbear from referring to the economy which would have been effected, in the conveyance of coal to the east end of the metropolis, had a line laid out specially for that purpose a few sessions ago fortunately received the sanction of Parliament. He had been much struck with the fact stated in the Paper, of the far greater destruction of the rails on the down-hill inclines of the Great Northern, over those on the up-hill inclines with an equal amount of traffic; for he confessed that, if he had been asked whether there would have been more destruction to the rails on the up-hill inclines, subjected as they were to the full tractive power of the wheels of the engine, or when going down-hill with less tractive force, he would have expected the wear and tear to have been greater upon the up-hill inclines; the contrary effect, however, simply showed the enormous percussive effects due to speed in destroying the rails.

With regard to the observations made by Mr. Vignoles, upon the importance of using rails without chairs, and also what had fallen from Mr. Hemans, advocating the same kind of rail, it occurred to him—first, that in order to make a rail of this kind equally stiff with the ordinary double-headed rail, it must be equally deep; and if that were so, with the long slender stalk presented by such a rail, he thought it not so well adapted to meet the lateral strain arising from heavy locomotives, as the double-headed rail, which was supported more directly against lateral force by the ordinary railway chair.

Mr. Bessemer said, an important question had been raised, with reference to what was to be done with the old steel rails. The question was one of great importance, when they considered the first cost of steel rails. It had been partly answered by Mr. Siemens, who said that a ton of old steel rails could be melted in his furnaces with a ton of small coal. But it had been found that, with 8 cwt. of coke a ton of old steel rails could be melted in a cupola, and be carbonized to such a degree, as to make them run from the furnace in the condition of white pig iron, and by a subsequent operation be remanufactured into the Bessemer metal. Another way was to put into the converting vessel one ton of old rails, and with the excessive temperature there generated, they would be melted and form part of the new charge of steel. But each of these plans had serious disadvantages, inasmuch as the new portion of metal so obtained was only in its first stage of manufacture, while the metal of the old rails had already passed through every stage. The rail itself had undergone all the operations of hammering, rolling, cropping, and the cost also of several heatings and wear and tear of furnace, and at last was brought into the condition of wrought steel. It was not wise, therefore, to convert such wrought metal again into the unwrought or ingot state. Hence he found that the most advantageous mode of working up old rails was to roll them into plates or bars of another section. An example of what could be made from the crop end of a rail was exhibited, in the shape of a sheet of steel 9 feet long by 1 foot wide. That was metal cropped from the ordinary end of a steel rail, and passed through the rollers; if the crop end had been put in crossways between the rolls, it would have been increased in width, and formed a sheet 6 feet long by about 3 feet wide. Hundreds of tons of these sheets were now manufactured in Sheffield, in great variety of size and thickness, the crop ends of the rails being sold for this purpose at £7 10s. to £8 per ton, notwithstanding the imperfect state of a portion of each crop end.

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[1] *Vide* "High Speeds." A Letter to the Right Hon. T. M. Gibson, M.P. By G. R. *Stephenson. 8vo. (Tract,* vol. cxxvii.) London, 1861.

To revert again to the old rails: a yard of the old rail from the Chalk Farm station had been rolled into small round rods at Sheffield, with a loss of not more than 2 or 3 per cent. in weight. These rods, several of which were exhibited, could be used for many purposes. Having incurred an expense of £2 to £3 per ton for the rolling, they would be worth £18 per ton at the present market price; and in that way the old rails became in fact more valuable than new ones. At all events, ordinary tin-plate bars of charcoal iron, of the same sectional area and form as a rail, when passed through plain and flat rolls, were worth £13 per ton; and this metal, which was much better in quality for rolling into tin plates, would be worth at least £12 per ton, after the rail had worn out seven or eight ordinary iron rails.

New railway bars in steel had generally been compared with iron ones of the same weight, and 84-lb. double-headed rails appeared to be the favourite type of rail for that purpose. Perhaps at first it was better to keep to the same scantling, merely replacing the iron with steel; but now that the great durability of the steel rail had been proved, it behoved those who regretted its first cost, to ascertain how far the first cost of the rails could be reduced by diminishing the weight, rather than by unduly diminishing the profits of the manufacturer. Mr. Kirkaldy's experiments showed that, as a beam supported on bearings 5 feet apart, the ordinary 84 lb. iron rail sustained a weight of 5 tons to the square inch of cross section, while the steel rail stood 10 tons to the square inch under like conditions. As the bearing surface of the rail need not be decreased in proportion as the general structure was decreased, it became necessary to ascertain what weight of steel per yard represented the same bearing power as the iron rail and the same resistance to cross strains as a given weight of ordinary iron rail. Taking, then, the fact that the tensile strength of the steel rail was nearly double that of the ordinary rail, these experiments, as far as they went, showed, he thought, that the weight of the steel rail might with safety be reduced by one-third. He believed a steel rail of 56 lbs. per yard, instead of 84 lbs., would bear a heavier strain than an ordinary iron rail of the latter weight, without either deflection or permanent set. Assuming, then, the price of steel rails to be £14 10*s.* per ton, and ordinary iron rails £7 10*s.* per ton, taking off one-third of the weight would bring the steel rails within about 43*s.* per ton of the cost of ordinary rails, and the old steel rails would be worth at least £10 per ton when done with. The necessary weight of steel rails was a point which should undergo strict investigation. Nor was that all. The first cost of the rail was not the only thing to be calculated. The rails had to be carried to their destination, and the old rails had to be taken away; then there was the turning of the rails as they became worn; indeed the labour consequent on the cost of the frequent renewals of the iron rails was far more than equivalent to the first cost of steel. The injury to the rolling stock must also be greater where the rails gave way at certain parts. The frequent concussions from that cause must assist in wearing out the wheel-tires, and at the same time do much injury to the rolling stock. These matters were important in an economical point of view. Then, again, the iron rails were a source of danger to the traffic of a line, from the number of times they had to be lifted. All parts of the line had to be lifted at some time or other, and when that was done, between the intervals of passing trains, it was a great source of danger; and he thought this point also required further investigation. In a matter of this kind it could hardly be expected that everybody would be of the same opinion, as there were old notions which it was difficult to overcome. When steam navigation had been proved to be a success on rivers, Dr. Lardner regarded the difficulties of ocean steam navigation as almost insurmountable. He quite admitted that, before a line of railway was laid with steel rails throughout, further proof was required, to enable the proper form and weight of a steel rail to be determined, and that point could best be effected by the members of the Institution. Just previous to the introduction of this Paper, he had proposed to undertake a series of experiments, to determine what strains ordinary Bessemer steel would sustain in practice. No one thing was more wanted than that. A good deal had been said about tensile strength, but very little about compressive strength. Mr. Bessemer would like to undertake a series of elementary experiments, in the first instance, so as to give means to establish correct formulæ, and then to construct some girders of a size to set the question at rest for ever. He should be happy to have the assistance of the Council of the Institution in this matter, because he wished the results to be made known for public information; and if the Institution, through some of its members, would witness those experiments, and verify the facts as proved, it would afford valuable information, which at the present time was much wanted.

Mr. HAWKSHAW, Past President, said, he quite concurred in one observation in the Paper, that as much progress had not been made in the improvement of the permanent way, as in other matters connected with railways. That had not arisen, in his opinion, so much from the want of knowledge of what was necessary to make a good permanent way as from notions of false economy. As he had remarked on a previous occasion, when similar questions had been raised, it was impossible to decide between different plans of permanent way, by statements of what had arisen on particular lines, unless informed of all the circumstances of each case. Take, for instance, the observations with regard to the Midland Great Western Railway of Ireland, when it was pointed out that a rail of a certain form, and a permanent way of a certain description, after eighteen years' wear, were still in tolerable condition. But he could point to rails of another form—double-headed, for instance, with cast-iron chairs—which, after as great or a greater lapse of time, were in an equally good condition. In fact, statements to the effect that the rails on some railways had lasted eighteen years, without any information as to the number of wheels that had run over those rails, and other necessary facts, led to no useful results whatever. He had laid double-headed rails over which trains had been running for twenty years, and he had laid similar rails, where the traffic was much larger, which had been worn out in half the time; therefore unless the number of vehicles which passed over the rails was stated, no useful conclusion could be arrived at. He agreed that the double-headed rail was subject to deflection; but so at present was every other kind of permanent way. If the rail was laid on longitudinal bearings it deflected. This could only be remedied by greatly strengthening the rails, greatly strengthening the sleepers, and by greatly improving and increasing the ballast; in proportion as this was done would the deflection be diminished.

The first railway he was connected with—the Manchester and Bolton Railway—was laid with the flat-bottomed rail on longitudinal timbers about the year 1834, and for the last twenty years, or more, he had been using that rail, as well as double-headed rails. In Russia, in particular, he had used the flat-bottomed rail on longitudinal timbers, because it made a cheap permanent way, and was sufficient for traffic at moderate speed. He believed that as perfect a road could be made with double-headed rails, cast-iron chairs, and cross sleepers, as with any other description of rails; but he admitted that there were other questions to be considered. In fact, as regarded the weight of the rails, scarcely any advance had been made. For the last twenty years Engineers had used rails of 75 lbs. to the yard, though locomotives had in that time been greatly increased in weight. There had been little change, with the exception that the sleepers had been laid a little closer, and the fish-joint had been introduced. He believed the first desideratum was to add to the weight. If it was wished to run at high speeds with locomotives of double the weight, it was plain that the weight of the materials which had to resist impact must be increased. The rails, sleepers, and ballast were nearly the same as they were twenty years ago.

With regard to steel rails, he thought their use was only a question of time, and that they would be adopted as steel tires had been. It was a better material; the difference in cost was not very great, and he thought Mr. Bessemer was wrong in suggesting, as an inducement to use steel rails, that their weight should be reduced. Mr. Hawkshaw recommended that the weight of the steel rail should not be less than 70 lbs. or 80 lbs. per yard. If reduced to 50 lbs. or 55 lbs. per yard, with locomotives weighing 30 tons or 35 tons, running at 40 miles or 50 miles an hour, steel rails would be a failure. Therefore, those who were considering whether to use steel rails had better adopt the proper weight, because weight was an important feature, and it was that in which they had failed. He was already using steel rails to a limited extent, and he hoped to do so with success. He would express his thanks for this able Paper, which did the Author the greatest credit, and was, on this particular subject perhaps the best that had ever been brought before the Institution.

Mr. Richard Johnson felt, as the railway with which he was connected had been mentioned in a prominent manner in the Paper, it might not be improper in him to say a few words. He could confirm the statements in the Paper with reference to the durability of the rails on the Great Northern line, and he might say, that for the last five years he had been more or less considering the advisability of recommending to his Directors the use of steel rails. At the present moment they had in use, in round numbers, about 2,000 tons; namely, through the Peterborough station for 2 miles, which had been in work about eighteen months; also through the Doncaster station, and about 500 tons at the London end of the line. He had been engaged during the last few weeks in preparing a calculation (Vide Appendix to the Paper, Table 14) to show at what point it became economical to use steel rails,—for that seemed to be the object which they wanted to arrive at; and he found, taking steel rails at £14 per ton, they were cheaper year by year, considering the period of twenty years' duration, than guaranteed iron rails at £9, with a wear of eight years. When he said guaranteed, it had for some time past been the custom of the Great Northern Company to buy rails with a guarantee; the traffic being heavy, the Directors thought it wise to ask for a guarantee from the makers; and for the last five years they had had a five or a seven years' guarantee with most of their rails.

The calculations he had prepared went to show, that steel rails at £14 per ton were cheaper year by year, as before stated, than iron rails at £9 per ton. They were cheaper in the first instance, he might say. Dealing with a single mile of rails, he found, after adding interest on the outlay, that the cost of a single mile of steel rails for the first year was £148 19*s.* 6*d.* as compared with £152 17*s.* 1*d.*, the cost of iron rails guaranteed for seven years, and supposed to wear eight years; and, similarly, that throughout the whole of the period of twenty years, the outlay for steel rails would be much less than for iron. But there was a further view of this subject, to which, owing to its great importance, he was anxious to direct attention. Taking the main line of the Great Northern railway from London to Doncaster, the Leeds, Bradford and Halifax, the West Yorkshire, and the West Riding divisions, also the Nottingham line,—all of which the Company now maintained,—they had something like 243 miles of double line, or 486 miles of single line. Taking the life of an iron rail at eight years (by supposing it to live one year beyond the seven years' guarantee), he found that about 61 miles of single line would have to be relaid every year; that was to say, the whole 486 miles of single line in eight years; and the cost of that, if iron rails were used, would be £85,400 per annum. Now came the question, how would the account be affected if steel rails were adopted? It came out, that for steel rails at £14 per ton, the expenditure would be £110,837 per annum for the eight years, till every part of the line had been relaid with steel rails. The result was, that during those eight years the steel rails would exceed the cost of iron rails, (reckoning interest on the outlay) by £255,046; but, having relaid the whole with steel, a period was then arrived at when he presumed there would be a little rest. For the next twelve years, he repeated, there would be a state of comparative rest; but then this, what he might call debt, of £255,000 would have to be paid; and he found, that in addition to the paying off of this debt, the question of re-sleepering the steel rails would have to be considered. The sleepers would last about ten years. He calculated that for re-sleepering each portion of the 486 miles at the end of about ten years, the yearly cost would be £21,020. Now, at the end of eight years there was a debt of £255,000; to pay off which it would be necessary to expend something like £27,240 per year; but in addition there would be the further sum of £21,020 a year for re-sleepering, making an annual outlay for twelve years of £48,460. It would easily be seen, that during this period the advantage of having used steel rails was becoming apparent, for had iron been employed the outlay would have been £85,400 a year; therefore, when once the period of eight years was passed, there was a difference in favour of steel over the whole line of something like £36,940 per annum. These figures had astonished him. Taking into consideration all the expenses, he had charged the steel rails with £519 per mile for re-sleepering, allowing for a proper proportion of broken chairs, keys, and the like. The result was, that there was a balance, after the eighth year, in favour of steel, of £36,940; on which annual excess, for the purposes of comparison, interest also should, of course, be reckoned. With regard to his own experience in the maintenance of various kinds of permanent way, he was in favour of the double-headed section of rail. There were on the Great Northern many miles of flat-bottomed rails on longitudinal sleepers, but after being in work for twelve years they required to be relaid. The rails of the double-headed section on the Loop line, 72 miles in length, which was opened in 1848, were 72 lbs. to the yard; these rails had been in use eighteen years, and, with the exception of the renewal of 4 miles, they were in very fair working order.

Mr. F. J. Bramwell said, in reference to Mr. Phipps's ingenious theory in support of the opinion, that the wear of the rails was as the square of the speeds, that he was inclined to think that the end of the calculation had not been reached, as it was assumed that the displacement of material must be equal at all speeds, and that if it were done at double velocity, it must take four times the power to do it, and therefore the wear must be four times. Was it not probable that the material was not displaced equally for all speeds, but that at the higher speeds there was less displacement, because the displacing force had a shorter time in which to act? As the resistance of the air increased as the square of the speeds, and as the whole resistance on a level was compounded, principally, of that of the air and of the work on the rails, if the wear of the rails were as the square of the speeds, ought not the whole power required to draw a train to be also as the square of the speeds? Practically this was not the case, and therefore the portion representing the work on the rails could not increase as the square of the speed. It seemed to him, therefore, that the theory on that point could not be accepted.

As to the reason why a suspended joint was better than a joint upon a chair, he might remark that if it were wanted to hammer out a bar of iron cold, the operation would not be begun by hammering at the middle of the bar, but the end would be attacked as the most vulnerable point; the reason being, that any particle in the middle of the bar had the support of the particle on each side of it, while at the end of the bar there was support on one side only. The same reason applied to the joints of rails. It must be evident, that the end of the rail was the most vulnerable point, and therefore, the part which, of all others, should not be over an anvil, such as a chair, but should be over a void, as when so placed, and supported only by the fish plates, it would yield under the hammer-action of the train, and not get punished. But when the ends of the rails were on chairs, then they got hammered out, as was evident by their widening out into the fan shape, so almost invariably seen when the joints were supported on chairs; but when suspended joints were employed, the ends of the rails were found to be hardly widened out at all, even after long use.

Mr. Phipps explained, that he was perfectly aware, when he propounded the doctrine of the destructive effects of speed being as the square of the velocity, that the objection would be made of its not corresponding with the usual notion respecting friction, namely, that the friction of solid bodies was as the simple velocity and not as the square; but it was quite easy to conceive that whilst the major part of the resistance on railways, exclusive of the resistance of the air, was simply as the velocity, the remaining part of the resistance, containing the destructive element he had referred to, might increase in the ratio of the square.

Mr. W. H. Barlow said, there were one or two points to which he wished to refer, more especially as to the time of duration of an iron rail. It was stated in the Paper to be three years, with a traffic of 63,000 tons. Now from his experience on the Midland Railway, he had reason to suppose the wear of a rail was from 100,000 to 150,000 tons, depending upon weight, speed, and other circumstances; and if it was so low as 63,000 tons, he thought there must be some defect to be accounted for by other causes.

In connection with the destruction of permanent way, there was one element which had not been previously referred to: that was the imperfect fitting of the parts. He had noticed one or two cases of that. In one instance, where the line, or part of it, was relaid with sleepers of superior quality, he was surprised to find within twelve months a report was sent to him, that the chairs were burying themselves into the sleepers. On inquiry it turned out that in a fit of economy, the old spikes had been used in relaying the new chairs. These spikes had been worn at the necks, and the consequence was motion of the chairs, which gradually became indented into the sleepers. Another example was in an endeavour to fish old rails with new fish plates. He confessed that fishing was of great benefit; but it would not do everything, and it would not do to fish old rails, as movement took place, which acted with great disadvantage.

On the question of experiments on steel, he agreed as to the great importance of getting reliable information on the subject. Two or three years ago, he obtained permission to make use of the Government testing-machine at Woolwich Arsenal, for the purpose of experiments on steel. These were carried to a certain length, and included tension, compression, transverse strain, and torsion; but unfortunately, the machine was not upon that scale which could bring out sufficiently satisfactory results. The experiments on tension were pretty clear, and agreed with those described by Mr. Berkley. The experiments on compression were better, inasmuch as they were made upon cylinders of 1½ inch in diameter, and the results were corresponding. The experiments on transverse strain did not agree, as they showed the deflection of steel to be as great as that of iron; but the capability of the former, of being bent to a greater extent before the elasticity gave way, was very great indeed. The differences in these respects showed the necessity for further inquiry into the subject. He should be happy to assist in any experiments for ascertaining the strength of steel under various strains, for which purpose Mr. Kirkaldy's machine appeared to afford great facilities and advantages.

Mr. F. W. WEBB said, in a short time arrangements would be completed at Crewe for the manufacture of 350 tons of steel per week, 300 tons of which would be used for rails. At present there were 50 miles of steel rails in use on the London and North Western Railway, and about 3,000 tons of the compound, or steel-headed rails. At Crewe, the main line, on both sides of the station, had been laid with steel rails. Having recently examined those laid in November, 1861, over which 52,191,859 tons had passed, he found the wear of the rails had been $\frac{5}{16}$ths of an inch. The results of the wear of these rails did not quite come up to the rails at Chalk Farm, but there had been a good deal of shunting over these rails, as upwards of 19,000,000 tons of the total tonnage were attributable to engines and tenders shunting at the goods sidings, &c. The greatest weight on any pair of wheels was 10 tons 10 cwt., which would tell more severely upon the rails than the lighter weight per wheel of the wagons. He had also examined the two rails which were made in 1862, and were shown in the International Exhibition by Mr. Bessemer. They were

35 feet in length, and were laid on the departure side of the Crewe station, on the up-line, on the 10th March, 1863. There had passed over these rails 18½ million tons, and the wear of the rails had been $\frac{3}{32}$nds of an inch. In the latter case there had been no great amount of slipping or breaking; in the former case there was a considerable slipping of the engines and breaking of the tenders and vans that passed over the rails.

As the discussion had in some measure turned on the attachment of the rail to the sleeper, he would state that, in 1859, Mr. Ramsbottom introduced on the London and North Western Railway wrought-iron chairs and keys, which had been working successfully, in lengths varying from a quarter of a mile to two miles of road at Bletchley, Sudbury, and on the Crewe and Chester line, &c.; nearly the whole of the rails, however, were laid with the ordinary fish-joint. Mr. Ramsbottom subsequently proposed and introduced a fish-joint without bolts, which stood very well, no instance of working loose having occurred. In this plan, a wrought-iron key, long enough to reach from chair to chair, was placed on each side of the joint. In the length laid at Crewe he had found no instance of the keys having become loose, and on inquiry of the plate-layers, he ascertained that only two keys had worked loose, and that was shortly after being laid. This method of suspending the rail from the chair had proved very successful. The rail was perfectly uninjured by the chair, and the rail could be turned, if it was thought desirable to use both the top and the bottom tables. At the time these chairs were first made the cost was £9 per ton, but since then the machinery had been so much improved, that they could now be produced at a much cheaper rate. It was in contemplation, by the London and North Western Company, to employ some of the old iron rails for re-rolling into chairs, instead of using cast-iron chairs. As the rail was suspended in the chair, on the upper web, there was no bottom bearing, so that the bottom table of the rail remained uninjured. In his experience he had not found rails break after being turned. The chief defect was the jolting motion in consequence of the indentation. No accident had occurred on the London and North Western through turning the rails.

Mr. Joseph Cubitt said, on the Great Northern Railway when new iron rails were first turned, after being about four or five years in the road, they broke to a very great extent, but he had never experienced it to the same extent in any other case. He supposed the metal had become deteriorated by the rolling.

Mr. Webb said, in his case the rails were chiefly re-rolled ones, and they were found to be very fibrous in the middle of the section.

Mr. T. E. Harrison said, the result of his experience with regard to turned rails was different to that mentioned by Mr. Cubitt. He had had rails turned constantly for years, and by adopting the plan of using a wooden cushion, which prevented indentation of the rail by the chair, he had not had reported to him a single instance of turned rails having broken. There must, therefore, be something beyond the mere turning which led to the, he believed, general impression that turned rails were sure to break.

There were some points suggested in the course of this discussion, which induced him to offer a few observations upon the subject generally. In the first place, Mr. Bessemer remarked that steel rails might be rolled of lighter weight, so as to reduce the cost to the same amount as iron rails. Now, for his part, he would never advise any railway company intending to adopt steel to follow that suggestion; because the weight of iron rails had been gradually increased, till they had arrived at 80 lbs. or 82 lbs. to the yard as a maximum; and it was probable even heavier rails might have been adopted, but the manufacturers seemed to be of opinion, that beyond that weight it was not possible to insure a rail absolutely solid and sound. He thought, by using steel for the heavier section of rail of 80 lbs. or 82 lbs. to the yard, that would only be another step towards perfection in the permanent way, which all who had to maintain lines of railway must look upon as a most essential object.

With regard to the use of steel rails, that was a question which ultimately with all railway companies must be reduced to a question of pounds shillings and pence; and though there were numberless cases in which iron rails did not last more than three years, yet there were instances within his own experience in which they lasted for twenty years, and then the question of compound interest became an essential element in the calculation. It was clear, that unless the cost of steel rails was much reduced, it could not be expected that they would be universally adopted; but at the same time, the instances in which they had been, and were daily being, used with great economy were very numerous—as at stations and places where there was a great deal of running of engines backwards and forwards. In such cases where ordinary rails would not last more than three or four years, from his own experience of steel rails (not Bessemer's make) there was three or four times the wear of ordinary rails with absolute certainty. The price of steel rails—as was the case with all new manufactures—had been rather high, but he found it was gradually going down. He had recently contracted for 500 tons of steel rails at £12 10s. per ton, which was getting towards a more moderate price, and as that went on, he had no doubt the use of these rails would be extended. He recollected having paid as much as £17 per ton for rails made of refined iron by a special process; but in those days the weight was not more than about 30 lbs. to the yard; then there was no hesitation as to the cost, the only anxiety being to have the best material. The original rails on the Newcastle and Carlisle Railway cost £17 per ton. When taken up, after a number of years' wear, and offered for sale, the demand for them was so excessive, that twenty times the quantity could readily have been sold, but rails of that quality had not been made during the last twenty years.

As to the form of rail and the mode of construction, Mr. Harrison stated, that he had taken up rails of every variety of form. Rails laid on the Hull and Selby line by the late Mr. Walker, thirty years ago, had been taken up within the last three or four years, and he had to consider the desirability of re-laying the road upon the same plan. The circumstances, of course, after a period of thirty years, were entirely different. The traffic had increased enormously, and, looking to all the circumstances, he came to the conclusion, that laying the line with cross sleepers, double-headed rails and cushions was infinitely better than laying it on the original plan; and on the North Eastern line, though there were formerly a great many miles on that system, yet at the present moment there was not a single mile of it. Before determining not to use it, he thought it necessary to go fully into the question, examining not only those who had charge of the permanent way as foremen, but those who had the actual maintenance of the road. In some cases, with a small traffic, it might be a useful kind of line; but looking to all the circumstances, his conviction was that, in the long run, the cross-sleeper line would be found to be the best. The flat-bottomed rails had been laid both on longitudinal and on cross sleepers on the Hull and Selby line, but they were not fish-jointed. The whole of the timber had been subjected to some preservative process, and the longitudinal timbers were so sound, that he actually laid a new set of rails and chairs upon the old sleepers that had been down for twenty years. There appeared to be a prejudice against creosoting, but he for one still adhered to it. He certainly thought there must be something peculiar which had induced those who had hitherto used creosoted sleepers to discontinue their use. In his own experience, he found no sleeper was better for wear than the ordinary Scotch fir sleeper creosoted. It was tougher than others, and would stand the resetting of the chairs, and pins might be driven into it two or three times without splitting. The great defect of the ordinary Baltic sleeper cut down the middle, was the splitting from the pins; but notwithstanding that, he thought it was a mere question of wear. Such a chair as Mr. Hemans had described, with so small a base, would be sure to wear into the sleeper. He had adopted a base of chair at least half as broad again as that; and if the chair had a large base, and was firmly bedded on the sleeper, his experience went to show, generally speaking, that the sleepers would last for a great number of years. There were creosoted sleepers still in use on the Stockton and Darlington line which had been down for more than twenty years. Then when a sleeper became split or indented by the chairs, there were many other useful purposes to which they could afterwards be applied. The North Eastern had an enormous amount of sidings. With 1,200 miles of main lines there were 705 miles of single line of sidings; and sleepers that were no longer useful for the main line were, if creosoted, applicable for the sidings; therefore to discontinue creosoting was, from his experience, an unwise policy. On an extensive railway there was always some purpose to which worn creosoted sleepers might be beneficially applied.

As to the asserted additional wear of the rails on a down incline, no doubt when running down an incline, the rails had a tendency to go down the incline themselves. But having lately examined the diagrams,—which had been kept for many years, and were similar in principle to those exhibited,—showing the wear of the rails, and the dates at which they had been renewed, on every portion of the North Eastern Railway, he found, that though on some of the inclines, the steepest being 1 in 120, there was a slight difference in the wear of the down line, yet it was so slight that he thought the increased wear upon the down incline on the Great Northern could not be attributed to the fact of its being on an incline; but it appeared to him to be owing to the much heavier weight of traffic to London, including the whole of the large mineral traffic. Then there was a further cause which, on the Great Northern, might have some effect. There were many tunnels which were blocked if there was anything in them, or a train immediately preceding, and the train could not be stopped without the application of the breaks. In travelling on that line, he had found it to be frequently the case that, from tunnel to tunnel, the breaks were applied, and that no doubt helped to wear the rails, and he attributed the additional destruction of the rails to that cause, more than to the fact of its being a down incline. He found further, that between York and Darlington, where there was a large mineral traffic towards York, there was unquestionably a difference in the wear of the up-rails; in that case the speed in both directions was equal. For 45 miles the ruling gradient was 1 in 1,000, therefore the theory of the steep gradient could not be applied in that case; and though no doubt the traffic towards York wore more than that coming from the south towards Darlington, yet the difference in the wear was less than he would have expected. A curious fact had been recorded by the resident engineers of the northern and southern divisions of the North Eastern line, viz., that the men who acted as platelayers in the northern district of Northumberland, would do a great deal more work than those who were engaged in the southern districts of Yorkshire. In the one case the men seemed to work with a natural vigour; they stripped to their work and seemed as if their whole soul was in it; but as they got towards the south, the same energy and love of the work was not manifested as in the north of Northumberland. Whether there was the same difference in the amount of work got out of the men as they came further south he could not say.

In conclusion, having had full opportunity of going into all the details, he did not think a Paper had ever been presented to the Institution which had been prepared with more accuracy, or with more complete detail, or with a greater determination to make it a perfect one. For himself he would say, that he felt under great obligations to the Author, for having brought so important a subject before them in so admirable a manner.

Mr. G. W. **Hemans** explained, that his suggestion with regard to the obvious advantages of continuous bearings for the permanent way had been condemned upon what, he thought, were false premises. It appeared to be assumed, that the permanent way he recommended had been tried, taken up, and condemned. He believed that system of permanent way had never been tried, in a perfect form, and that it was deserving of a trial. A heavy rail with a flat surface at the bottom, laid on longitudinal sleepers, and well fished at the joints with deep fishes had never, to his knowledge, been laid and subjected to a fair trial, except, in a not very perfect manner, for a short distance at the Victoria Station, and which he believed was a very successful piece of permanent way.

Mr. **Bessemer** said, he feared he had scarcely explained clearly his views with reference to the lightness of steel rails. He intended it to be understood, not that the rails must necessarily be lightened very much, because it appeared that the increased traffic and great weight of the engines were such, that the present iron rails did not admit of the reduction being made; but rather to lead to the inference, that as steel was much stronger as a beam, and was capable of sustaining a much greater weight than iron, without deflection or permanent set, so, in estimating the actual weight of steel and iron that was required to sustain a given load, the two metals ought not to be reckoned as equal pound for pound with each other. If it was not desirable to lighten the steel rail, then in any comparative estimate, the cost of a much heavier iron rail must be taken as its equivalent.

Mr. J. S. **Crossley** said, having paid considerable attention to the permanent way of the Midland Railway, he found that the average duration of iron rails was sixteen years; the minimum life was ten years; and, where there was a very heavy traffic, about twelve years. The rails having a duration of ten years were bedded on cast-iron sleepers, and suffered such rapid wear on the lower side that they could not be turned. The indentation was very considerable, from the narrow base of the bearing surface. In his own experience he never knew of a rail breaking from being turned, unless it was bad iron. He did not find that the necessary result of turning a rail, was that it must break; but when the rails were indented, there was that disagreeable motion which was caused by passing over the indented surface of the rails. On the Midland Railway the relaying of the rails, including interest on first outlay, was effected for 11*s.* per ton per annum. If steel rails at £18 per ton were used, it followed that the interest of the money rendered that material unavailable for the general purposes of ordinary lines. In certain positions, such as the entrances to stations, &c., no doubt they were useful and profitable. If steel rails, at £12 per ton, were employed, then the interest was greater by 1*s.* per ton per annum; therefore they ought only to be used in exceptional cases. But supposing the steel rails to last for ever—which he did not imagine was claimed for them—he found the calculation stood thus. Iron rails could be re-rolled for £3 5*s.* per ton. The question was the interest of the money; taking £7 per ton as the average cost of the rails, that would be 7*s.* per annum, the re-rolling 65*s.* divided by the number of years the rails lasted. If their life was sixteen years, it would be 4*s.* per ton, and if only eight years, it would be 8*s.* per ton. If a rail only lasted eight years, steel rails at £15 per ton would be the more profitable; but his own experience was, that on lines where the traffic did not exceed sixty or seventy trains a day each way, he did not think a rail of good quality would wear out in less than twelve years, and that the average life was sixteen years. He could confirm the statements of Mr. Harrison in this respect. On the Thame Valley line, rails of 68 lbs. to the yard had been in use for twenty-four years; but the quality of the iron of course had much to do with the duration of a rail.

With regard to creosoting, he was one of those who had given it up, because he did not think it answered commercially. At Grimsby good rectangular Baltic sleepers, 9½ inches by 4¾ inches, could be purchased for 2*s.* 4½*d.* or 2*s.* 5*d.* each, and those 10 inches by 5 inches for 2*s.* 9*d.* each. If 1*s.* was spent in creosoting, that at compound interest for fourteen years would be 2*s.* He had sleepers that had lasted for sixteen years, and thus there was 2*s.* 2*d.* out of the 2*s.* 4*d.*, which would pay for a new sleeper, and he got thirty-two years' wear out of the two sets of sleepers as against twenty under the creosoting process. He thought that creosoting increased the tendency to split, and on lines where the chairs had too small a bearing, the sleepers were worn through. He had seen as much as 2 inches or 2½ inches of indentation of the chairs into the sleepers: creosoting was no protection against that. He did not think the rotting of the sleepers was the only element that had to be considered in the wear of sleepers. There was the trituration of the wood, which creosoting did not prevent, and there was further the tendency to split. His own opinion was, that the money which the creosoting would cost was more than adequate to replace the injury from decay which creosoting prevented. On these grounds he had discontinued to creosote. For bridge timber and piles creosoting was valuable, for preventing the attack of the worm, but for sleepers he did not think it paid, and pounds shillings and pence were more urgent than science, in regard to the materials used in the construction of a railway. Whatever tended to reduce the dividend was not looked upon with favour by Boards of Directors. By the use of steel rails at £14 per ton the dividend on so much capital as was represented by the rails would be reduced from 5 per cent. to 2½ per cent.; but if a 70 lb. rail of steel could be adopted with equal safety and advantage as an 80 lb. rail of iron, it went very much to raise the value of steel rails in the construction of railways. From his own experiments he believed that a 70 lb. steel rail was as much to be depended upon as an 80 lb. iron rail, though he thought it better not to go back in the weight of material, because if an 80 lb. iron rail could be rolled, the same could be done in steel: the only question was, was it worth their while to do it? No doubt an 80 lb. steel rail would make a very strong road; but at the end of ten years it would be found that a great deal more had been paid for it than for an ordinary road. He considered on the whole, that the use of steel rails at present would be confined to places of great wear—as the entrances to stations and shunting-places—and there, he thought, for the present it must stop.

It was said that old steel rails were worth £10 per ton to convert into plates, &c., which were worth more money than the rails. How was it they were not made into plates in the first instance? as that was an inducement to manufacturers to jump over the intermediate twenty years. He thought as it cost about £3 to re-roll iron rails, it would cost at least £5 or £6 to re-roll steel, and assuming that a steel rail would last two and half times as long as an iron one, that was the measure of the value of steel. If it cost £12 10*s*. it would be worth £7 as scrap.

Mr. BROTHERHOOD inquired, whether Mr. Crossley intended his remarks, with regard to non-creosoting, to apply to England alone, N°. 6.

600
50
500
50
400
50
300
50
200
50
100
50
18 47
Average No of men per mile
JUN.

N°. 7.

600
50
400
50
300
50
200
50
18 4
Average No of men per mile

were sufficient to contradict that statement, and the many patents used and tested by the Engineers on most of the leading lines of railway also went to show its fallacy. After all the experiments, it appeared they had come back to the old system of the chair with the key. He had adopted, on a length of 10 miles, iron keys fastened by a small bolt passing through the jaws of the chairs. These had been in use for eight years without requiring any renewals, neither had any become broken.

Fig. 2.

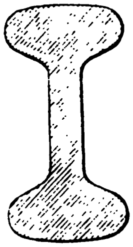
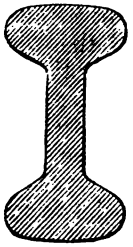


Fig. 3.



FURNESS AND MIDLAND RAILWAY.

Steel Rail, 76 lbs. per yard. Iron Rail, 80 lbs. per yard.

¼ full size.

Mr. H. W. SCHNEIDER said, being connected with the Barrow Hematite Steel Company, he would make a few remarks upon steel rails, particularly with reference to the commercial value of those rails, because he held that everything must be reduced to pounds shillings and pence, and unless it could be shown incontestibly that steel rails would give at least as good a dividend, they would be put on one side and iron would be continued. He laid it down as an axiom, that they had no right to take a given weight of iron rail, and then assume that steel required to be of the same weight. What had to be done was to test the relative merits of steel and iron, and take that weight of steel which represented an equivalent value of iron. If it was necessary to increase the weight of steel, it was equally necessary the weight should be increased in iron. Following out what Mr. Bessemer had justly said, it would be found, if it were possible to reduce the weight of steel, it was simply because a 72 lb. rail in steel was practically equivalent to an 84 lb. rail in iron for all the purposes of the daily traffic; but then came the more important point, whether the steel rail, in the course of a given number of years, would pass through such an amount of punishing, that at the end of that time it would represent a commercial value greater than that of the iron rail. He dissented from the statement, that for £7 per ton at the present time a rail could be got in England worth anything at all. No Engineer would venture to say, he would put down rails at £7 per ton, that would last sixteen years, where there was any large traffic. He had made a calculation that the ordinary wear of a good iron rail at £8 5*s.* per ton would be fourteen years with a fair traffic; and he was convinced, from experiments he had made upon steel, and looking to the greater effect of oxydation upon iron than upon steel, that steel would wear for an almost unlimited period; but he was contented to assume that a steel rail would wear out three iron rails, lasting fourteen years each, and this brought him to the commercial point of the question. Without going through all the calculations he had made, he would say, supposing a steel rail cost £13 a ton, at which he believed steel rails might be produced, it would be found that, compared with iron rails at £8 5*s.* per ton, there would be a saving of £8 per ton of iron rails at the end of forty-two years, reckoning 5 per cent. compound interest during that period, and adding £3 10*s.* each for two renewals of the iron rail necessary to make it last the forty-two years. He assumed that at the end of the forty-two years, the steel rail would be worth £7 per ton, not £10; but he went further and said, following up that calculation to a ten years' life of an iron rail, for heavy traffic, and assuming, as he might do, without contradiction, that a steel rail would last for forty years, against four renewals of ten years each of iron, there would be a saving of £15 per ton of iron rails, or £1,500 per 100 tons of iron in the steel over the iron. In that calculation he had assumed that 85 tons of steel rails would practically represent 100 tons of iron rails. He did not enter into the question, whether it was possible to reduce the weight of the rail, but he said if it was necessary to have steel rails of 84 lbs. to the yard, it was equally necessary that the weight of the iron rails should be increased from 84 lbs. to 100 lbs. to the yard.[1]

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[1] The comparison between steel rails in England against iron rails stands thus: taking steel rails at £13 per ton and iron rails at £8 5*s.* per ton, and assuming that steel rails weighing 15 per cent. less than iron are stronger than iron rails, that iron rails of the best quality, with ordinary wear, will not last more than fourteen years, that it costs £3 10*s.* to convert a ton of old rails into an equal weight of new, and that steel rails for this work will wear out at least three iron rails:—

IRON RAILS.

		£.	*s.*	*d.*
100 tons of iron at £8 5*s.*		825	0	0
14 years at 5 per cent. interest on £825—£41 per annum .		574	0	0
		1,399	0	0
100 tons reworked at £3 10*s.* =	£350	350	0	0
First cost . . .	825			
	£1,175			
14 years' interest at 5 per cent. on £1,175—£58 per annum		812	0	0
Carried forward .		£2,561	0	0

With regard to the presumed folly of steel manufacturers making steel into rails and selling them at £13 per ton, when the old rails could be worked up into another form, and be sold at a higher rate, that was, no doubt, upon paper a very pretty theory, but in practice it had this essential defect, that it was not economical, for this reason; he held that the Bessemer process was one of those scientific operations which required large capital, great skill, and works of great magnitude, before it could be hoped to carry out the process with anything like satisfactory results. The consequence was, having to deal with quantity, the manufacturer must look to that article which would take up the largest quantity and weight, and that undoubtedly was rails. But, nevertheless, the fact was perfectly true. He had himself seen the ends of rails shorn off, utterly unfit for practical purposes, put under a 3-ton hammer, split in two, heated, and wrought into a miner's pick, which had lasted as long as five picks made from iron, for which £22 per ton had been paid; the iron pick requiring steeling, and the other only requiring to be put into the fire and sharpened. This proved that the refuse of steel rails might be converted into a very valuable article, which sold at the moment for a higher price than the rails. Again, he could not see why it should be inferred, that whilst iron rails could be re-rolled for £3 10*s.*, it would cost

					£.	*s.*	*d.*
Brought forward					£2,561	0	0
First cost and one renewal	£1,175						
Second conversion	350				350	0	0
	£1,525						
Interest—14 years, on £1,525, at 5 per cent.—£76 per annum					1,064	0	0
					£3,975	0	0
STEEL RAILS.							
85 tons of steel at £13		£1,105	0	0			
5 per cent. interest = 55 × 42 years		2,310	0	0			
	£.	3,415	0	0			
Value of steel at the end of 42 years; 85 tons at £7 per ton	595						
Value of iron ditto 100 tons at £3 10*s.*	350						
		245	0	0			
					3,170	0	0
Saving on steel equal to £8 per ton, or £800					£805	0	0

In any case this saving is much increased by the cost of relaying the rails and the superior strength; but in the case of foreign lines, and India especially, where there are not the same facilities for reworking the iron rails, this saving is multiplied to a large extent. The question of carriage is also an important one. At stations, the advantages of steel are too self-evident to require any remark, and it is by no means an established fact, that steel rails will not last much beyond forty-two years, and on the other hand, it is certain that where there is a large [traffic,

£5 per ton to re-roll steel rails. All the expensive portion of the process of the manufacture of steel rails had been passed before the material reached the rolling mill. If an old steel rail was worked in the same way as an old iron rail, he was satisfied it could be done, if not quite as cheaply as iron, within a very few shillings per ton, and these few shillings would be added to the steel, because the waste was upon the higher-priced article, and therefore it must be added to the cost of the waste; but the cost of the re-manufacture was otherwise the same in steel as in iron. But the chief objection to steel rails he admitted was their price. It was well known that, in all new articles, before competition was introduced into the manufacture, there would be a cost additional to what the same things could afterwards be produced at; but without going into the question of the actual cost of steel rails, he thought it was hopeless to expect, that steel rails would ever be reduced to anything like the price of iron rails, as the finest qualities of pig iron had to be used, and the process was an expensive one. He believed that £13 per ton was a fair price, and he trusted that it was not a price which would deter Engineers from making use of steel rails; but beyond that, the price of steel rails would not, in his opinion, be reduced for a lengthened period to come. In making Bessemer steel, extreme care must be taken with reference to the manufacture of the pig iron in the first instance, and in the selection of the ore for the purpose, all hematite not being equally

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traffic, iron rails will not last more than ten years, when the advantages are still more apparent, thus—

IRON RAILS.

	£.	s.	d.
Iron rails, first cost	825	0	0
Interest at 5 per cent. = £41 × 10	410	0	0
	1,235	0	0
Original cost and first renewal £1,175	350	0	0
5 per cent. = £58 × 10	580	0	0
	2,165	0	0
Original cost and two renewals £1,525	350	0	0
5 per cent. = £76 × 10	760	0	0
	3,275	0	0
Original cost and three renewals £1,875	350	0	0
5 per cent. = £93 × 10	930	0	0
	4,555	0	0

STEEL RAILS.

		£.	s.	d.
Original cost	1,105			
5 per cent. = £55 × 40	2,200			
	3,305			
Less increased value at the end of 40 years	245			
		3,060	0	0
Saving equal to £15, or £1,500		£1,495	0	0

valuable for this pig iron. In the next place, having selected the ore, it was desirable to test every pig after it came from the furnace, to avoid passing over from the iron works to the steel works any iron that was not of the best quality for the purpose for which it was intended.

The results of a few of the experiments made by Mr. Kirkaldy, as to the tensile, crushing, and shearing powers of the steel manufactured by the Barrow Hematite Steel Company, were recorded in the following Tables:—

TABLE 1.

ELONGATION and SET, under a gradually increased PULLING STRAIN of FOUR Bars of Cast Steel forged to 1¼ inch diameter, and turned to 1¼ inch.

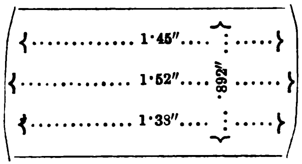
	STRAIN in lbs.																
	40,000	42,000	44,000	46,000	48,000	50,000	52,000	54,000	56,000	58,000	60,000	62,000	64,000	66,000	68,000	70,000	72,000
	·083	·087	·092	·098	·107	·129	·158	·188	·238	·310	·435	·498	·584	·684	·730	·818	·86
Set	·044	..	..	..	·057	..	·090	..	..	..	..	..	..	..	..	..	..
	·079	·084	·087	·090	·100	·115	·138	·171	·218	·281	·348	·389	·452	·502	·564	·635	·6
Set	·041	..	..	..	·052	..	·085	·113	..	..	..	..	..	..	..	..	..
	·080	·082	·086	·088	·091	·095	·098	·100	·228	·265	·378	·441	·490	·545	·603	·686	·7
Set	·044	..	..	..	·048	..	..	·051	..	·204	..	..	..	..	..	..	..
	·082	·085	·089	·092	·095	·098	·102	·112	·226	·385	·492	·520	·582	·666	·732	·825	·89
Set	·045	..	..	..	·050	..	..	·053	..	..	..	..	..	..	..	..	..

STRAIN in lbs.—*continued.*						Ultimate Strain.		Fractured.				Elongation in 14 in.	
										Difference.			
74,000	76,000	78,000	80,000	82,000	84,000	Total.	Per Square Inch.	Diameter.	Area.	Area.	Per Cent.	Total.	Per Cent.
·910	·984	1·05	1·25	1·47	1·84	99·528	81·108	·87	·5945	·6326	51·5	2·68	19·1
Set	..	..	..	..	..	..	..	..	..	..	..	..	..
·778	·895	1·02	1·18	1·34	1·62	85·376	69·575	·84	·5541	·6730	54·8	2·29	16·4
Set	..	..	..	..	..	..	..	..	..	..	..	..	..
·850	·992	1·07	1·28	1·46	1·82	85·024	69·288	·81	·5153	·7118	58·0	2·48	17·3
Set	..	..	..	..	..	..	..	..	..	..	..	..	..
1·04	1·25	1·43	1·56	1·98	2·26	84·848	69·145	·80	·5026	·7245	59·1	3·36	24·0
Set	..	..	..	..	..	..	..	..	..	..	..	..	..
						Mean	72·279			Mean	55·9	Mean	19·2

TABLE 2.—RESISTANCE, under a Gradually Increased CRUSHING STRAIN, of Four Cylinders of Hammered Cast Steel, turned to 1¼ inch diameter, and of the same height.

STRAIN in lbs.															Ultimate Strain.		Remarks.
80,000	88,000	96,000	104,000	112,000	120,000	128,000	136,000	144,000	152,000	160,000	167,700	175,500	183,300	191,100	Total 195,000	Per Square Inch.	
·060	·075	·090	·110	·129	·152	·180	·205	·239	·270	·299	·325	·350	·380	·405	·419	158·924	Entire.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·396	..	
·062	·078	·095	·114	·138	·168	·190	·215	·248	·275	·309	·328	·362	·384	·401	·422	158·924	Ditto.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·401	..	
·058	·074	·090	·109	·129	·155	·183	·214	·247	·278	·308	·340	·368	·393	·420	·434	161·557	Ditto.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·411	..	
·050	·062	·079	·095	·114	·138	·159	·182	·215	·239	·268	·296	·327	·350	·379	·392	158·924	Ditto.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·368	..	

Fig. 1.



In the first test, with 195,000 lbs., the cylinder had assumed the dimensions shown in Fig. 1.

When replaced in the machine, under a strain of 258,750 lbs., it changed to the dimensions shown in Fig. 2.

Fig. 2.

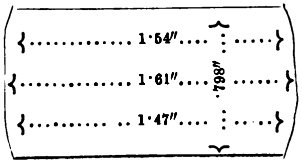


TABLE 3.—Resistance, under a gradually increased Double Shearing Strain, of Four Bars of Hammered Cast Steel, forged to 1⅓ inch, and turned to 1¼ inch diameter.

STRAIN in lbs.																			Ultimate Strain.	
60,000	64,000	68,000	72,000	76,000	80,000	84,000	88,000	92,000	96,000	100,000	104,000	108,000	112,000	116,000	120,000	125,000	130,000	135,000	Total.	Per Square Inch.
·058	·064	·072	·078	·484	·095	·104	·112	·122	·133	·142	·154	·168	·184	·202	·221	·250	·280	·305	140·810 { 70·405 70·405	57·380 57·380
·080	·086	·092	·100	·106	·112	·122	·128	·134	·141	·150	·158	·168	·176	·190	·205	·231	·262	·298	137·620 { 68·810 68·810	56·079 56·079
·069	·080	·086	·092	·102	·109	·118	·125	·132	·142	·152	·158	·172	·182	·198	·216	·238	·270	·309	137·150 { 68·575 68·575	55·889 55·889

TABLE 4.—Resistance, under a gradually increased Buckling Strain, of Four Bars of Hammered Cast Steel, forged to 1½ inch diameter, turned to 1¼ inch. Length = 10 diameters.

STRAIN in lbs.								Ultimate Strain.			Remarks.
32,000	36,000	40,000	44,000	48,000	52,000	56,000	60,000	Decrease.	Total.	Per Square Inch.	
·022	·025	·028	·032	·036	·040	·320	·375	0·506	63·040	51·377	Entire.
Set	..	..	·009	..	..	..	..	..	..	..	
·031	·036	·040	·162	·275	·320	·431	..	2·430	57·720	47·041	Entire.
Set	..	..	·139	..	..	..	..	..	..	..	
·020	025	·028	·030	·033	·039	·150	·184	0·852	61·472	50·930	Entire.
Set	..	..	·008	..	..	..	..	..	..	..	
·021	·025	·028	·031	·035	·118	·132	·150	0·535	63·856	52·042	Entire.
Set	..	..	·008	..	..	..	..	..	..	..	

The particulars of two experiments upon double-headed steel rails, weighing 73 lbs. per yard, manufactured for the Furness and Midland Railway, given in the next Table, would serve to show, that the great drawback attributed to steel, of being liable to breakage by sudden impact, did not exist:—

TABLE 5.—RESISTANCE to Deflection and Set, under a gradually increased BENDING STRAIN, of two double-headed Steel Rails. Distance between the Supports, 60 inches.

	STRAIN in lbs.														
	13,000	15,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000
..	·089	·109	·132	·151	·171	·192	·219	·296	·885	1·35	2·13	2·72	3·31	4·05	4·91
Set	·010	..	·021	..	·030	..	·051	·152	·701	..	..	..	..	..	..
..	·095	·116	·145	·162	·180	·204	·272	·720	1·14	1·75	2·39	3·22	4·04	4·68	5·54
Set	·012	..	·027	..	·038	..	·158	..	1·01	..	..	..	..	..	..

STRAIN in lbs.—*continued.*									Ultimate Strain.		Sectional Area Square Inches.	Remarks.
44,000	46,000	48,000	50,000	52,000	54,000	56,000	58,000	60,000	Total.	Per Square Inch.		
5·55	6·16	6·92	7·54	8·17	8·84	9·64	10·82	12·02	60·976	8·422	7·24	Canted Entire.
..	..	..	..	..	..	..	..	..	..	..	..	
6·12	6·90	7·72	8·65	9·54	10·52	..	..	..	55·040	7·602	7·24	Canted Entire.
..	..	..	..	..	..	..	..	..	..	..	..	

He exhibited a rail bent to an extent which proved its extreme ductility. He then referred to Mr. M'Clean's experiments on Barrow rails, one of which was shown; and as to the other, after the first bending the rail was straightened again and bent in the opposite direction; and after a second straightening, it was again bent double sideways, without producing the slightest fracture: all this was done cold.

In the course of the discussion mention had been made of a compound rail (partly iron and partly steel) as being, on the whole, better than either an iron rail or a steel rail, *per se*, inasmuch as it combined the hardness and wearing properties of the steel with the ductility and other properties which attached to iron, and there was a saving of cost: he ventured to disagree with that theory, for one reason; if an article could be obtained, equal to their highest requirements, in steel, he would adopt that material, because the difference in cost between a rail compounded of iron and steel, and one entirely of steel, could not be above half the difference between iron by itself and steel, by itself; and there was this disadvantage in the compound rail, that when it had to be remanufactured, it could be neither forged nor rolled with effect, because the properties of one part of the rail were essentially different from those of the other part. Therefore, commercially, the value of that rail in the market, when worn out, would be far less than the difference of the original cost of having the steel rail entire.

Mr. **Bramwell** inquired, whether it was to be understood, that there was a capability in the Bessemer rails of being piled and completely welded?

Mr. **Schneider** replied, that he had himself superintended that operation in steel of every size. He had seen steel bars put together and heated and passed through the rolls, and the weld was so perfect that he could not detect the junction. He had also seen the end of a miner's pick welded on to a new piece of Bessemer steel, in such a manner that when broken at the point of junction, it was impossible to distinguish where the weld took place. One of the great properties of the Bessemer steel was, that it would weld to itself as readily and as perfectly as iron would weld to itself.

Mr. **Webb** mentioned that, in 1860, he was unsuccessful in welding steel rails. About 50 tons of crop-ends were operated upon and rolled into rails, but though the operation seemed to have been perfect, the rails laminated.

Mr. **Schneider** added, that in 1860 hardly anybody in this country knew how to deal with the Bessemer metal. The class of metal produced then was not that which was produced now. Even Mr. Bessemer himself would admit that in 1860 his steel was very different from what it was now. What they claimed credit for now was, that they had succeeded in making steel which retained all the properties of steel with all the ductility of iron.

Mr. **R. Price Williams** said, the course of the discussion had been such as to render any reply from him almost unnecessary. He begged to thank the members for the manner in which the Paper had been dealt with, and for the approval which it had met with. He had the further gratification of thinking it had elicited a great deal of valuable information bearing upon the question, which more than compensated him for any trouble he had incurred. He could only further say, that he proposed to continue his investigations on this subject, and was anxious to impress upon the Engineers having charge of permanent way, that they would confer a great kindness upon him, by agreeing upon a little more uniformity in the mode of keeping the accounts. He would have been saved much time and trouble in compiling the information he had done, if all the permanent-way accounts had been kept on the same principle; at the same time he availed himself of the opportunity of thanking those gentlemen most sincerely, not only for the valuable information they had so readily afforded him, but also for the great kindness and encouragement he invariably had met with.

Mr. C. B. Lane begged leave, through the Secretary, to call attention to what had been designated as Mr. Phipps' ingenious theory. He maintained that a considerable class of the deteriorating effects produced by passing loads on the permanent way might be easily demonstrated to increase as the square of the velocity. He alluded to the effects arising from concussions, due to imperfect arrangements generally, but more especially to those arising from the absence of exact coincidence between the centres of gravity and centres of rotation of the wheels. Any unbalanced weights in these bodies would exercise a certain amount of deteriorating "labouring force" upon the rails; but "labouring force" was measured by the fraction represented by the formula $\frac{\text{weight} \times \text{by velocity}^2}{2 \text{ the acceleration of gravity}}$ in which the factor velocity occurred in its second power. Any one who would calculate the number of foot-lbs. wasted from this cause over a given space at two different velocities, would find the amount to vary as the square of these velocities; thus showing the theory referred to to be not only ingenious but true.

Mr. Fowler, President, said, in closing the discussion, as it had been protracted to a great length, he would be even more brief than he had intended. The Paper was a very valuable one, and had led to a most useful discussion, and from both a great deal of information had been obtained. But the discussion had perhaps ranged over too wide a surface to be quite so satisfactory on some points as was desirable. For instance, not only had there been discussed the question of the materials of the permanent way, whether these should be of iron, of steel, or of iron rails steeled, and whether the timber should be uncreosoted or creosoted, but also, widely and generally, though not so pointedly as was desirable, the different systems of permanent way at present in use had been taken into consideration. Opinions had, in fact, been expressed by nearly every speaker on the subject of the systems of permanent way, but, as a general rule, only incidentally to the other matter in the Paper, and not as part of a serious discussion upon the best system of permanent way, as a question of construction. He hoped at some future time, and before long, this subject of permanent way—more particularly as to the methods of designing and laying it down—would be thoroughly discussed at the Institution. From his own experience he was not prepared to admit, that the best kind of permanent way had yet been arrived at, even assuming that steel rails and creosoted timber were used. If it were true that steel rails would last forty-two years, and creosoted sleepers one hundred years, as contended for in the course of the discussion, that alarming item to railway shareholders of 'renewals' would practically disappear from future accounts. But even if that were happily the case, there were still other questions connected with permanent way which had been scarcely touched upon; for instance, whether longitudinal sleepers with the bridge rail, or longitudinal sleepers with the Vignoles rail, or the longitudinal road that in these days would be laid with the deep Vignoles rail with fished joints (for he believed that had never been laid in a manner, and of dimensions suited to the present weights and speed of traffic), or a cross-sleeper road with a double-headed rail on chairs, or the bridge rail laid as in Ireland, or the cross-sleeper road with the deep Vignoles rail with a good fish,—which of these methods, under different circumferences, might or might not be the best, was a matter he should like to be thoroughly discussed, and not as it had been (with no fault on the part of any one) incidentally to the other purposes of the Paper. There had been no opportunity of comparing one system with another, as the cases alluded to were not parallel cases. The light road taken up on the North Eastern, and replaced by rails of a heavier description and chairs with a wider base, was not a parallel case, or a real comparison. It was a remarkable circumstance that, except in this country, the Vignoles was almost the only form of rail used; and it was employed on the main lines of France, where the traffic was as heavy and the speeds as high, as on most of the main lines of railway in this country; while the rail which appeared to find so much favour here had been, on full trial, discarded by the Engineers of every other nation. There might be good reason for this, but it was clear there was something in this question which required to be further considered and further discussed. He had in his possession a mass of information as to the various systems of permanent way in use in every country in the world at the present time, which he should be happy to present to the Institution. It must not be thought that the subject of the permanent way of railways was by any means exhausted; for valuable as the information already obtained undoubtedly was, much yet remained, which might be profitably discussed on a future occasion.

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